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Barriers to Lean Enterprise Transformation: A Case Study of the F-16 Avionics Sustainment System

by

Benjamin Michael Brandt

B.S., Aerospace Engineering (1998)
Embry-Riddle Aeronautical University

Submitted to the Engineering Systems Division
In Partial Fulfillment of the Requirements for the Degree of
Master of Science in Technology and Policy

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ABSTRACT

Instituting basic principles of *lean thinking* can help transform the U.S. Air Force's sustainment system by substantially improving its efficiency and effectiveness. One of the immediate outcomes of viewing the sustainment system through "lean lenses" is the identification of numerous barriers impeding the system's transformation. These barriers are caused by a complex array of institutional, organizational, financial, technological, and policy and regulatory structures, as well as practices, established by the Air Force, Department of Defense (DoD) and the Congress. An example of the policy and regulatory environment within which the sustainment system operates is the Congressionally-mandated workload allocation limitation known colloquially as the "50/50 rule," directly impacting the Air Force's ability to meet customer demands.

Within this larger context, this thesis addresses the following key questions: (1) How should the F-16 avionics sustainment system be modified to achieve significant performance improvements through lean enterprise transformation; (2) What are the major barriers impeding the system's transformation through the adoption of lean principles; (3) How can these barriers be effectively overcome to derive the benefits of lean transformation; and (4) What are the key benefits that can be expected through lean enterprise transformation?

This thesis employs the Transition-to-Lean (TTL) Roadmap developed by the Lean Aerospace Initiative (LAI) at MIT as an analytical framework to analyze the progress of the F-16 sustainment system towards becoming a lean enterprise. To gain a better understanding of the system, a Value Stream Map (VSM) of the current F-16 avionics sustainment system is developed. The VSM has helped to identify many of the organizational, financial, informational, institutional, policy and regulatory barriers. It has also aided in the identification of various types of *waste* resulting from the use of non-value added steps in the system.

The VSM-related research has led to four major conclusions. First, there is considerable waste in the system. Second, the sustainment system at the depot-level lacks a customer focus, which is an important aspect of *lean thinking*. Third, lack of availability of repair parts and materials seriously hinders the system's efficiency and effectiveness by both impeding *flow*, an important lean concept, and by causing substantial waste through cannibalization of serviceable parts and components. Fourth, insufficient system-wide information availability and visibility, as well as poor data quality, undermine the determination of actual customer needs at the flight line.

Based on these conclusions, the thesis offers a number of recommendations. The recommendations focus initially on enhancing flow throughout the system and improving the customer focus of the system. They also stress the adoption of new performance measures or metrics to motivate the behavior of people and organizations within the system to foster system optimization rather than local optimization. The recommendations further involve restructuring and closer integration of key organizational units engaged in the funding and production of maintenance services supporting the combat units. Finally, the recommendations address the issue of information availability to help elevate the system's ability to gauge the customer's real needs and requirements on a timely basis

In addition to the recommendations, this thesis closely examines the impact of the "50/50 rule" on both government-owned sustainment entities and commercial providers of maintenance, repair and overhaul (MRO) services, by examining the stance the public and private organizations have on the rule. It is found that the public organizations and private companies have similar views on the rule, but present their views from different positions. This assessment indicates that lean transformation of the Air Force sustainment system would enable it to be in full compliance with this workload allocation provision.

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FOREWORD AND DISCLAIMER

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The views expressed in this thesis are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the U.S. Government.

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LIST OF ABBREVIATIONS AND ACRONYMS

2LM – Two-Level Maintenance
3LM – Three-Level Maintenance
ACC – Air Combat Command
AFB – Air Force Base
AFCAIG – Air Force Cost Analysis Improvement Group
AFFHM – Air Force Flying Hour Model
AFI – Air Force Instruction
AFMC – Air Force Materiel Command
AFMCI – Air Force Materiel Command Instruction
AFPD – Air Force Policy Directive
AFSC – Air Force Specialty Code
AFWCF – Air Force Working Capital Fund
ALC – Air Logistics Center
AMU – Aircraft Maintenance Unit
AMXS – Aircraft Maintenance Squadron
ATS – Avionics Test Station
AWM – Awaiting Maintenance
AWP – Awaiting Parts
BOM – Bill of Materials
CAMS – Consolidated Aircraft Maintenance System
CANN – Cannibalization
CLIOS – Complex, Large-Scale, Integrated, Open System
CLS – Contractor Logistics Support
CND – Cannot Duplicate
COTS – Commercial-Off-The-Shelf
CRI – Consolidated Reparable Inventory
CSI – Consolidated Serviceable Inventory
DBOF – Defense Business Operations Fund
DI – Displays and Indicators Shop
DIFM – Due-In-From-Maintenance
DLA – Defense Logistics Agency
DMAG – Depot Maintenance Activity Group
DMAPS – Depot Maintenance Activation Planning System
DMBA – Depot Maintenance Business Area
DMT – Dual Mode Transmitter
DoD – Department of Defense
DREP – Depot Repair Enhancement Process
DRILS – Depot Repair Information Local Server
DWCF – Defense Working Capital Fund
EXPRESS – Execution and Prioritization of Repair Support System
FLSS – Flight Line Supply Support
FW – Fighter Wing
GAO – General Accounting Office
GD – General Dynamics
GSD – General Support Division
ICS – Interim Contractor Support
ILM – Air Force Director of Maintenance
INW – In-Work
ITN – Inventory Tracking Number
ITS – Inventory Tracking System
JIT – Just-In-Time
LNA – Low-Noise Assembly
LSI – Lean Sustainment Initiative
LRT – Logistics Response Time
LRU – Line-Replaceable Unit
LTL – Less-Than Truckload
MAJCOM – Major Command
MASS – MICAP Asset Sourcing System
MC – Mission Capable
MDS – Major Defense System or Mission Design Series
MFL – Master Fault List
MICAP – Highest Priority Backorder
MIT – Massachusetts Institute of Technology
MLPRF – Modular Low-Power Radio Frequency
MMTL – Material Management Team Lead
MRO – Maintenance, Repair and Overhaul
MRSP – Mission Readiness Spares Package
MSD – Materiel Support Division
MTBF – Mean Time Between Failures
MXG – Maintenance Group
MXS – Maintenance Squadron
NDAA – National Defense Authorization Act
NFF – No Fault Found

LIST OF ABBREVIATIONS AND ACRONYMS (continued)

NHA – Next Higher Assembly
NMCS – Not-Mission Capable Due to Supply
NRTS – Not-Reparable This Station
NVA – Non-Value Added
NVAE – Non-Value Added but Essential
OO-ALC – Ogden Air Logistics Center
OS – Operations Squadron
OSD – Office of the Secretary of Defense
PDM – Programmed Depot Maintenance
PMT – Production Materiel Technician
PP – Processor/Pneumatics Shop
QDR – Quality Deficiency Report(s)
QPM – Quality Performance Measures
RBL – Readiness Based Leveling
RF – Radio Frequency Shop
RP – Receiver Protector
RSP – Readiness Spares Kits (same as MRSP)
RSS – Regional Supply Squadron
RTS – Reparable This Station
SBSS – Standard Base Supply System
SCM – Supply Chain Manager
SMAG – Supply Management Activity Group
S/R – Shipping and Receiving
SRU – Shop-Replaceable Unit
SSC – Shop Service Center
TNB – Tail Number Bin
TPS – Toyota Production System
TTL – Transition-To-Lean
U.S.C. – United States Code
VA – Value Added
VSM – Value Stream Map
VTMR – Variable-To-Mean Ratio
WAP – Workload Approval Package
WCD – Work Control Document
WIP – Work-In-Process Inventory
WR-ALC – Warner-Robins Air Logistics Center

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Chapter 1: Introduction

The Air Force sustainment system is a complex system that spans several maintenance and logistics organizations. This research seeks to better understand the sustainment system by following the movement of end-items (components) the Air Force refurbishes to support its aircraft fleets. The process starts with the removal of failed end-items from an aircraft, and the actions that are taken to move the item on- and off-base to depot repair for refurbishment. The process ends with the placement of refurbished end-items into the serviceable inventory for later use. An important goal is to reduce the sustainment pipeline time at the base and depot so that the sustainment system operates more efficiently and effectively. This reduced pipeline time will help to increase the capacity of the system, allowing the Air Force to improve its responsiveness to the needs of the combat forces. To the extent that the Air Force's workload allocation falls below 50 percent under the Congressionally-mandated "50/50 rule" (more on this below), as a result of realized efficiency gains through the employment of lean principles, the Air Force may well have the option of bringing back to the "organic" sustainment system maintenance, repair and overhaul (MRO) work currently performed by commercial MRO providers supporting the Air Force. This is not to say that the primary goal here is to expand the Air Force's share of the total MRO workload, but increased efficiency may well provide the Air Force with such an option.

The "50/50 rule" is established by Title 10, Subtitle A, Part IV, Chapter 146, sections 2464 and 2466 of the United States Code. Section 2464 states the necessity for a "core logistics capability that is government-owned and government-operated to ensure a ready and controlled source of technical competence and resources necessary to ensure effective and timely response to a mobilization, national defense contingency situations, and other emergency requirements." [10 U.S.C. 2464(a)(1)] The core logistics capabilities are "those capabilities that are necessary to maintain and repair the weapon systems and other military equipment." [10 U.S.C. 2464(a)(3)] In order to accomplish this, the mandate sets a percentage limitation on the amount of funds made available for contracting of depot-level maintenance and repair workload. This percentage is "not to exceed 50 percent of the funds made available in a fiscal year to a military department or a Defense Agency for depot-level maintenance and repair workload." [10 U.S.C. 2466(a)] Depot-level maintenance and repair is also defined in the provisions as "material

maintenance or repair requiring the overhaul, upgrading, or rebuilding of parts, assemblies, or subassemblies, and the testing and reclamation of equipment as necessary, regardless of the source of funds for the maintenance or repair or the location at which the maintenance or repair is performed." [10 U.S.C. 2460(a)]

As of fiscal years 2000 and 2001, the Air Force did not meet the Title 10 provisions. (GAO 03-16, p.8) The total amount of funding for depot maintenance activities in these years was $6.181 billion, and $6.84 billion respectively. (GAO 03-16, p.8) Of this, 51.5% in 2000 and 51.9% in 2001 of this funding went to private firms in the completion of depot maintenance as defined. (GAO 03-16, p.8) The Air Force forecasts its allocation to remain at almost exactly 50/50 until the year 2006. (GAO 03-16, p.8) Therefore, by improving the flow of end-items and SRUs (assemblies and subassemblies) through the sustainment system, namely depot-level maintenance, capacity can be increased, since items will not take as long to repair. Therefore, the Air Force will be able to reclaim some of the workload and funding it has contracted to private firms in order to maintain a core logistics capability. Before the research could start it was necessary to understand the Air Force maintenance concept, and to determine how to better understand the Air Force sustainment system.

1-1 U.S. Air Force Maintenance Concept:

"The overall mission of Air Force maintenance", as stated by Air Force Instruction (AFI) 21-129, "is to provide aerospace systems ready to fly and fight, and to sustain mission-ready equipment at the time and place it is needed." "Maintenance tasks are divided into two categories, on-equipment (maintenance performed directly on the aerospace vehicle or support equipment) and off-equipment (maintenance performed to removed component parts of the vehicle or equipment)." (AFI 21-129, p.3) "These categories may be preventive or corrective in nature, and may be performed at the wing, regional or depot level." (AFI 21-129, p.3) A change in level of repair typically reflects the difficulty of repair, with the most difficult and unique of repairs occurring at depot level.

> *This research focuses mainly on the off-equipment repair of F-16 avionics components (end-items), and the process involved in repairing these end-items at the three levels identified.*

However, "the Air Force is shifting its maintenance philosophy, procedures, and organization to accommodate a two-level approach," which would eliminate the intermediate repair of end-items and consolidate it to a regional, depot or contractor repair facility. (AFI 21-129, p.3) This transition to two-level maintenance (2LM) "supports the Air Force's objectives of reducing manpower, equipment, facilities, and mobility footprint while still meeting its Global Engagement mission objectives." (AFI 21-129, p.3) The move to 2LM relies on using "state-of-the-art communications, item visibility, and fast transportation systems, thereby moving unserviceable end-items to and through the regional, depot and/or contractor repair activity." (AFI 21-129, p.3)

While not all items are selected for 2LM, there is a decision process to help determine which items should be selected. "The first step in the process", as outlined in AFI 21-129, "provides three sorting techniques to begin the overall analysis of assets for possible transition to 2LM." (AFI 21-129, p.6) These techniques focus on combat readiness as the primary criteria, potential savings associated with eliminating manpower tied to intermediate level repair, and avoiding the cost of buying high acquisition cost items. Cost savings must take into account residual tasks that must remain at the unit, such as F-16 Cannot Duplicate (CND) screening/quick repair. (AFI 21-129, p.6) Also, 2LM candidates should be highly reliable, have a relatively low demand rate, have sufficient spares, and be easy to transport. (AFI 21-129, p.6) An example would be aircraft avionics as these items are generally small, and many are highly reliable and have long mean times between failures (MTBF).

"The main objective of Air Force Logistics", as established by AFI 21-129, "is to maximize operational capability by using high-velocity, time-definite processes to manage mission and maintenance uncertainty." (AFI 21-129, p.8) This provides the Air Force with short repair and delivery times, and reduced inventories and associated costs critical to the overall maintenance objective. (AFI 21-129, p.8) To improve operations of the reparable and/or serviceable pipeline, Air Force 2LM operations use: (AFI 21-129, p.8)

1. Fast, time-definite delivery transportation of end-items to and from the depot or other source of repair.
2. Expedited processing of reparable end-items to the appropriate depot repair shop, non-batch repair processes, and the use of express transportation to return serviceable end-items to the wing/installation or deployed location.

3. Expedited shipment of reparable end-items by the base to the appropriate depot.

These operations and processes enabling them are examined in this thesis through value stream mapping (VSM) of the F-16 avionics sustainment system, as noted below in greater detail. The introduction of 2LM does provide a variety of savings and operational improvements. However, if the underlying assumptions (e.g., short repair times) are not met, the system will not operate effectively, and this could hamper operational capability. To illustrate the process where unserviceable assets are moved from base to depot and back to the base, it is necessary to select a product and an analytical framework for performing the required analysis. This is discussed below in more detail. This research hopes to draw conclusions based on an analysis of the current system and provide recommendations for improvements to the 2LM process, which would lead to improvements in operational capability.

1-2 Selecting a Product

Since avionics were used as an example of where cost savings could be achieved by moving from a three-level to a two-level maintenance approach this research will focus on the end-to-end process F-16 avionics end-items follow to be repaired after they are taken off the aircraft at the flight line. This process will be referred to as the F-16 Avionics Sustainment System, since it deals with the continued sustainment (i.e., maintenance, repair and overhaul) of end-items that are made serviceable and returned to the system as refurbished end-items.

The F-16 Avionics Sustainment System encompasses the actions the end-items encounter at the flight line, base, and depot level. The entire Air Force sustainment system, including reparable avionics, structures, electro-mechanical, hydraulics and engines, is a closed-loop system that includes flight line base-level maintenance, backshop base-level maintenance, and depot-level maintenance. Supply and transportation, and logistics activities, such as requirement forecasting, connect all of these maintenance activities that ultimately service the real customer, flying operations. As avionics end-items become unserviceable (failed) they are removed from the aircraft, thus generating a requirement for a replacement. A replacement item is drawn from the Consolidated Serviceable Inventory (CSI), and placed back on the aircraft. The failed end-item is moved from the flight line to the base backshops for screening and quick repair, and if it is still unserviceable, it is immediately sent to its respective depot for repair. After the depot

repairs the end-item (if it is able), it is deemed serviceable, and moved into the CSI for eventual use by a flight line anywhere in the world when a requirement is generated.

Because the F-16 avionics suite comprises various types of avionics - radar, displays and indicators to name a few - there is a great deal of variability in demand depending on which particular avionics end-item is observed. Most of these avionics end-items, once they fail, will keep aircraft from being mission capable, because the aircraft cannot perform its mission without them. For the purposes of this research, selecting an end-item that is currently experiencing difficulties in a 2LM system seemed ideal. In this respect, particularly serious difficulties are faced in sustaining certain end-items. These end-items typically involve considerable awaiting parts work-in-process inventories. They are also often hard-to-repair due to lack of availability of the required repair parts and materials and have a history of high-priority backorders referred to as MICAP.

The Modular Low-Power Radio Frequency (MLPRF) end-item, which is a key component of the F-16's radar system, was selected for the following reasons. First, since it is a high-priority, high-visibility end-item, it was easier to gather information about the end-item. Second, its availability could readily be affected by the research, and thus have the most immediate effects on the sustainment system. A final reason for selection is that because the end-item is experiencing difficulty in flowing through the system, it would be easier to identify more overarching root causes of system sub-optimization that may be buffered by extra inventories that other end-items enjoy or other repair actions, such as piece-part cannibalization. The sustainment system that the MLPRF and other avionics end-items move through for repair is highly dependent on parts and funding being available for repair.

1-3 Selecting an Analytical Framework:

In order to observe the F-16 avionics sustainment system, it is necessary to have an analytical framework driving the analysis that can then serve as the basis for drawing conclusions and recommendations. For this research, the Lean Enterprise framework was selected because basic lean principles underlying this approach have been adopted as the main approach for bringing about large-scale systemic change throughout the Air Force, as exemplified by the Air Force's push for "Lean Now" initiative under the auspices of the Lean Aerospace Initiative at MIT. Lean principles originated nearly 50 years ago in Japan as World War II ended, and the Japanese

surrendered to the Allies. Toyota, which existed before and during the war was faced with a daunting strategic challenge. This challenge was how to catch up with U.S. industry, the world's most dominant manufacturing force at the time. (Murman, p.87) "Toyota's president, Kiichiro Toyoda, posed the challenge to his employees to 'Catch up with America in three years' in order to survive." (Murman, p.87) "He posed this challenge to Taiichi Ohno, then one of Toyota's key engineers, and today revered as the originator of the Toyota Production System (TPS)." (Murman, p.87)

Ohno identified the sources of success for U.S. automobile manufacturers, as well as the system's underlying weaknesses. (Murman, p.88) He observed "mass production – high-volume, large-lot production, with vast warehouses to store inventory, and a highly vertically integrated operation." (Murman, p.88) The mass production mentality was not right for the Japanese economic realities of the time. Therefore, Ohno developed "a dynamic process that unfolded over the next few decades" – involving the emergence of what today would be a part of *lean thinking* – "in response to the unique Japanese business challenges." (Murman, p.88) "A variety of solutions emerged to address particular limitations of the mass production model: innovations such as just-in-time (JIT) delivery, in-station process control, total productive maintenance, integrated product and process design, *kanban* method for material pull, and others." (Murman, p.88)

Lean thinking focuses on two key principles: eliminating waste and creating value. While both of these are important elements of lean, they are insufficient to comprise *lean thinking*. Therefore, Murman et al. defined lean thinking based on decades of scholarship and field observations. (Murman, p.89)

> *Lean thinking is the <u>dynamic, knowledge-driven</u>, and <u>customer-focused</u> process through which all people in a defined enterprise continuously <u>eliminate waste</u> with the goal of <u>creating value</u>.* (Murman, p.90)

There are several concepts embedded in this definition, so it is necessary to deconstruct the definition for further understanding. It is also important to note that lean principles did not emerge from the theoretical constructs of scholars, but are ideas first developed in practice and later sifted and recorded by scholars and other observers. (Murman, p.90) Deconstructing the definition will begin with focusing on two concepts: customer-focused and knowledge driven.

Customer Focused

"In a lean system, the customer provides the orientation for the entire enterprise, and represents what may be deemed 'true north'." (Murman, p.92) "Customer needs and expectations act as a *pull* upon the enterprise," and in the case of this research, from end-item refurbishment to capability enhancements and redesigns. This is meant to give customers the "right product at the right time and at the right price." (Murman, p.92) In the sustainment system, this could have several meanings. It could be the *pull* from the CSI in order to keep the shelves stocked in case of contingency and surges, or the *pull* of top-priority backorders, MICAPs, from the depot repair shops. The latter, backorders, is something that should not occur with increased customer focus. "The customer pull in production operations is reflected in the elimination of in-process inventory and the building of products in direct response to customer orders." (Murman, p.92)

Knowledge-Driven

"Being customer-focused requires the ideas and effort of an entire workforce, because it is impossible to eliminate waste or add value effectively without the full input of front-line workers, engineering design team members, office staff, and all others who touch the product, develop designs, or deliver services." (Murman, p.92-93) Mass production relies on the "innovation and improvement coming from a relatively small group of experts, with the rest of the workforce acting as interchangeable cogs in the production and design machines – and as a cost." (Murman, p.93) Lean thinking involves the entire workforce, the suppliers, and others as sources of knowledge, information, and insight regarding the elimination of waste and the creation of value. (Murman, p.93)

The avionics sustainment system involves numerous organizations, line-workers, and suppliers that could contribute to the lean transformation of the system. While customer-focus and knowledge-driven are two key principles of lean thinking, it is necessary to define two additional, and equally important concepts, *eliminating waste* and *creating value.*

Eliminating Waste

For a system or enterprise to be more customer-focused, "all forms of waste must be eliminated." (Murman, p.93) These wastes include: overproduction, work-in-process

inventories, and extra steps in accomplishing a task. (Murman p.93) Waste elimination allows an enterprise to cut costs, while also improving quality, safety, and responsiveness to changing requirements. (Murman, p.93) "The elimination of waste is a powerful way to shorten cycle times in the sustainment system by eliminating all steps that are unnecessary and do not add value, and thus enhance enterprise responsiveness." (Murman, p.93-94)

Often the words 'eliminate waste' are associated with eliminating jobs, but as noted in the previous topic, "the knowledge-driven nature of lean urges a focus on employees not as a cost, but as a source of ideas for eliminating waste." (Murman, p.94) Thereby, lean thinking recognizes employees as the most valuable resource. The 'Seven Wastes' are categories developed for manufacturing, but they can be adapted to any operation. They are: overproduction, inventory, movement (motion), waiting time, processing, rework, and transportation, not workforce or employees. (Murman, p.94)

Creating Value

"Every enterprise has many stakeholders," and each defines value a different way. (Murman p.95) Sometimes these values are shared or complementary, while others are in tension. Additionally, demands for immediate returns on investment push short-term values at the sake of long-term stability valued by the workforce and communities. (Murman, p.95)

"While there are many dimensions of value to an enterprise transformation," for this research it suffices to note that "lean thinking involves *learning to see value*." (Murman, p.95) "A powerful method for this is *value stream mapping*, where all 'value add' activities are traced in sequence through a given operation, and whatever does not add value is waste." (Murman, p.95) Therefore, lean thinking involves eliminating waste and identifying improvements that will help create value for one or more stakeholders. (Murman, p.95)

The final 'deconstructing' of the lean thinking definition looks at two additional concepts: *dynamic and continuous.* (Murman, p.95)

Dynamic and Continuous

Lean thinking from its roots is dynamic, and is an ongoing process. (Murman, p.95) "The continuous improvement (*kaizen*) concept has been a main thrust of lean production that began with Toyota and continues to be central to lean thinking." (Murman, p.95) "In Japanese, *kaizen*

means ongoing improvement based on knowledge from everyone – not just from experts, but from all managers and workers." (Murman, p.95) "Continuous improvement is a problem solving process requiring the application of a wide array of tools, methods, and practices." (Murman, p.95) In the aerospace and defense industries, *kaizen* has come to represent one-time innovative improvements and not continuous improvement. (Murman, p.96) While this is better than the status quo, it is far from the continual process that lean thinking relies upon.

These elements of lean thinking taken together represent a fundamentally different way of thinking. (Murman, p.96) This is in direct contrast with the mass production mindset, "in which the focus is on maximizing quantity, building 'buffers', increasing machine utilization, and reducing headcount." (Murman, p.96) Furthermore, mass production has established a segmented form of thinking that encourages separation and that limits efforts to link across an enterprise and across value streams. (Murman, p.96)

A Broader View of the Enterprise

Until recently, lean had been narrowly focused on manufacturing, but a full analysis of the evolution of lean thinking urges a broader view of lean, centered on the entire enterprise. (Murman, p.115) One author cited in *Lean Enterprise Value* stated, 'Improving the parts of a system taken separately is not likely to improve the performance of the system as a whole.' "While manufacturing operations have been the first area of lean thinking focus in the aerospace industry, it is increasingly clear that a focus across the entire enterprise is essential." (Murman, p.115)

The implementation of lean principles and a vision of an Agile Logistics program in the U.S. Air Force is pushing the use of lean thinking to improve both the acquisition and sustainment parts of a product's life-cycle. While most focus has been applied to the acquisition community, the sustainment community can achieve a great deal of value by using this analytical framework to employ lean principles. Using the lean thinking and lean enterprise analytical framework, system waste and value can be illustrated by conducting a Value Stream Map (VSM) of the F-16 avionics sustainment system. This will be the vehicle by which conclusions and recommendations will be made in order to improve the mission capability of the F-16 fleet, while reducing costs of end-items, and increasing customer value.

1-4 Value Stream Mapping as a Vehicle:

Because of the complexity and inter-relatedness of the F-16 avionics sustainment system it has been difficult for the Air Force to implement "lean principles" across the enterprise. There are several examples of "islands of success" in various sustainment systems, such as the F-15 wing refurbishment shop and C-5 depot maintenance, but few of these successes have extended beyond the boundaries of each shop. Therefore, this research takes a more enterprise-oriented approach to implementing lean principles through the use of the Lean Aerospace Initiative's Transition-To-Lean (TTL) Roadmap shown in Figure 1.1.

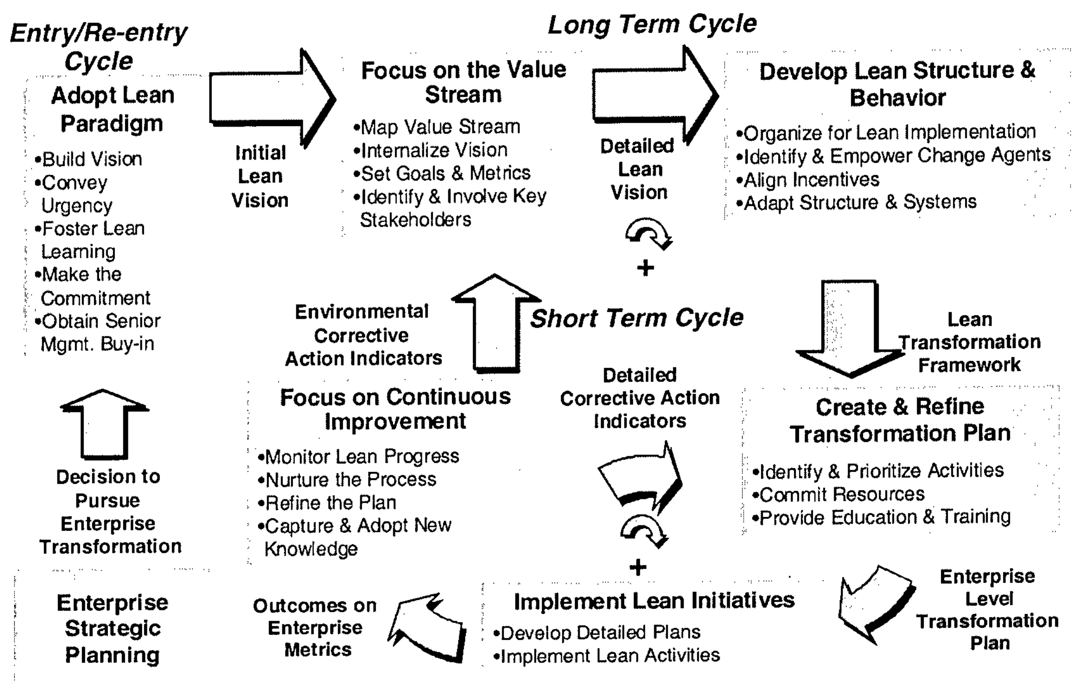

Figure 1.1: Transition-To-Lean Roadmap (Murman et. al., p. 155)

The TTL Roadmap begins with an entry and re-entry cycle of "Enterprise Strategic Planning" and "Adopting the Lean Paradigm" concepts. While these two concepts have not been fully deployed in the Air Force sustainment community, there has been a push lately towards adopting more and more lean principles, especially at the depot level by enhancing the flow of refurbished end-items through the depot repair shops. Most lean transformation work to date has been in aircraft structures-related depot repair, with only a few systems-related efforts. The most notable systems lean transformations are the F-15 avionics shop and Low-Altitude Navigation and Targeting Infrared for Night (LANTIRN) system at Warner-Robins Air Logistics Center

(WR-ALC). One of the reasons for this limited implementation is that the Air Force may have failed to include the entire process from base-level to depot-level and back again, and foster lean implementation across entire specific end-item's products and just focused on certain organizational processes. Therefore, the shops may have optimized their part of the sustainment system to the detriment to another part of the system.

This type of philosophy is based on a simple premise, as established by Womack et. al. in *Lean Thinking*, that "activities that can't be measured can't be properly managed, the activities necessary to create order and produce a specific product which can't be precisely identified, analyzed, and linked together cannot be challenged, improved (or eliminated altogether), and, eventually, perfected." They go on to say that "the great majority of management attention has historically gone to managing aggregates – processes, departments, firms – overseeing many products at once. Yet what is really needed is to manage whole value streams for specific goods and services." The first of five lean thinking principles that value stream mapping relies on is specifying the value you are trying to achieve. In the case of the F-16 Avionics Sustainment System, value is having serviceable avionics end-items immediately available at the flight line to replace failed end-items. However, this should not be accomplished by merely increasing inventory levels, but by shortening the depot repair time, and elimination of waste in the value stream as defined by the 'Seven Wastes' of lean.

Therefore, since the specified value is that of improving avionics availability, the focus becomes the refurbishment process of these avionics end-items by conducting a value stream map. Additionally, with the Air Force establishing a 'Lean Now' office to oversee lean transformations (e.g., Adopting the Lean Paradigm) it is a natural progression in the TTL Roadmap to begin "Focusing on the Value Stream". This focus can be guided by the initial 'lean vision' as established by the specified value of the F-16 avionics sustainment system. Focusing on the *value stream* includes mapping the value stream, but also has several other elements. These elements are internalizing the initial lean vision, setting goals and metrics, and identifying and involving key stakeholders. Once the entire value stream for each product is identified, the next step is to start eliminating the waste or *muda* from the system and creating value. Both topics pertaining to eliminating waste and creating value in a lean enterprise were outlined in the analytical framework section of this chapter.

Once these two steps (value identification and mapping, and waste elimination) have been accomplished, it is necessary to make the remaining value-creating steps *flow*. Introducing flow to the system involves three steps as a means to shift from traditional thinking to lean thinking, and breaks the boundaries of the organization. (Womack, p.21) The first step is to look at the entire process a product encounters, and reorganize the enterprise by focusing on the product itself. The second step, which makes the first step possible, is to ignore the traditional boundaries of jobs, careers, functions, and firms to form a lean enterprise removing all barriers to the continuous flow of the specific product. Finally, the last step is to rethink specific practices and tools to eliminate backflows, scrap, and stoppages so that the specific product can proceed continuously. (Womack, p.52)

In addition to *flow, pull* is important to the lean enterprise. The *Pull* mentality is based on the premise that the customer can pull the product from the enterprise as needed, rather than the enterprise pushing products, often unwanted, onto the customer. By letting the customer pull the product from the enterprise, the demands of the customer become more stable, and with flow, customers get what they want right away. (Womack, p.24) The best way to understand the logic and challenge of pull thinking is to start with a real customer expressing a demand for a real product and to work backwards through all the steps required to bring the product to the customer. (Womack, p.67) By having conducted a value stream map, this process allows us to easily identify the steps required to achieve customer pull. This pull system encompasses not only manufacturing, repair in this case, but also distribution practices. However, in order to fully implement lean thinking, the final principle is striving for *perfection*.

Perfection through continuous improvement is the acknowledgment that the lean transformation does not happen overnight, but requires a series of improvements that may take years. These improvements can come in the form of refining the definition of value, expanding the value stream, increasing the flow, and relying further on the customer to pull value from the enterprise. Therefore, a lean transformation does not happen once, but happens several times to each product and process stream, thus a continuous improvement atmosphere must be fostered by the enterprise.

This research demonstrates how to use value stream mapping as a first step in illustrating the closed-loop, highly inter-related sustainment value streams that make up ALC operations. To continue the Air Force's lean transformation by using the guidance offered by the TTL

Roadmap, it is necessary to conduct a value stream map of the various sustainment systems. However, since this system involves more than one organization, financial structure, information system, and policy and regulatory structure, it is necessary to identify possible lean transformation barriers in these contexts.

This thesis contains a value stream map of the F-16 avionics sustainment system (Chapter 3). Once the value stream has been mapped, system influences and barriers will be addressed (Chapter 4), wasteful practices will be identified (Chapter 5), conclusions drawn (Chapter 6), and recommendations made (Chapter 7) to establish the lean principles of flow, pull and perfection.

1-5 F-16 Avionics Sustainment System Background Information:

According to an Air Force Fact Sheet, the F-16 Fighting Falcon is a compact, multi-role fighter aircraft that is highly maneuverable and has proven itself in air-to-air combat and air-to-surface attack. Originally built by General Dynamics (GD) under contract from several NATO countries, the newest models are produced by Lockheed-Martin Corporation, which bought GD in the 1990's. There are four models of the F-16, the A and C models accommodate one pilot; the latter is an updated version of the former. The B and D models are two seat versions of their one-seat counterparts. The A/B model cost is valued at $14.6 million and C/D models are $18.8 million in fiscal 1998 constant dollars. It provides a relatively low-cost, high-performance weapon system for the United States and allied nations. Currently there are over 3,000 operational F-16 aircraft operated by 21 countries. The U.S. Air Force is the largest operator of the F-16, over 50% of the entire fleet, and oversees the continued sustainment of the F-16 for the U.S. and all other countries the aircraft has been sold to.

U.S. Air Force aircraft are being flown longer than they were ever intended, especially the F-16, and require an extensive support network, referred to as the sustainment system. This sustainment system encompasses both maintenance and logistics, which play key roles in the movement of end-items through the system. This sustainment system handles aircraft modification, retrofit and programmed depot maintenance (PDM), as well as consumable and reparable end-item acquisitions. PDM encompasses complete or partial tear-down of the aircraft for inspection, structural repair, and other systems maintenance.

The F-16 Avionics Sustainment System is an enterprise within the larger Air Force enterprise, and in order to understand how this (or any) sustainment system can transition to

being a lean enterprise, we need to understand the current state of the system. Therefore, the heart of this research is a value stream mapping exercise of the F-16 Avionics Sustainment System to help determine where "waste" exists and where value can be created in working towards a lean enterprise. In the value stream mapping process, organizational, financial, information systems, and policy and regulatory structures are identified as possible barriers to value creation. Identifying these possible barriers to a lean transformation will ease the "transition-to-lean" for the F-16 Avionics Sustainment System.

Currently the F-16 Avionics Sustainment System is highly fragmented into several "silos" of competing interest at the base and depot level. This is not an intentional fragmentation, but a result of the hierarchical command and control organization structure of the U.S. Air Force. The base-level repair and supply organizations are focused on keeping as many aircraft mission capable for operations, and will go to great lengths to achieve their goals. The depot-level repair goals are related to repairing items that; (1) are brought into the shops by automated information systems, and (2) the shops have negotiated to repair on a quarterly basis. However, it is also focused on shop efficiency and productivity as well as financial performance. Financial performance in a public organization is defined as operating within the established fiscal year budget, and can act as a constraint to the repair of end-items, as well as the acquisition of piece parts to repair these end-items. Unfortunately, these goals, while well intended, drive wasteful behaviors; they do not promote lean thinking. Actions, such as producing items not necessarily required by the "end customer" to maximize production efficiency tend to be focused more on financial performance than customer satisfaction.

The end customers, as defined in this research, are the F-16 flying operations squadrons. However, the depot repair shops' direct customer is the F-16 Supply Chain Manager; they interact directly with the CSI in the "selling" of serviceable end-items. Conversely, the flight line and base-level repair shops directly support flying operations, but the sustainment system cuts across these organizations in support of having mission capable aircraft.

Disconnects between "siloed" organizations and local optimization behaviors act against the principles of a lean enterprise. The six principles of a lean enterprise (as defined in *Lean Enterprise Value*) are: waste minimization; responsiveness to change; right thing at right place, at right time, and in right quantity; effective relationships within the value stream; continuous improvement; and quality from the beginning. (Murman, p.147) By effectively identifying the

value stream from the end customer's perspective, waste can be effectively reduced or removed from the system and provide value in a more responsive, agile, avionics sustainment system.

The value creation in the Air Force sustainment system is different from the typical private aerospace firms. Private firms are interested in providing "tangible returns on investment that shareholders rightly expect, and job satisfaction and lifetime learning that workers deserve", and "the sharing of benefits suppliers need if they are to continue operating as partners in good times and bad"[1]. (Murman, p. 3) In public organizations, such as the Air Force and the Department of Defense (DoD), there are no shareholders, except the taxpayer who pays no matter how the system is operated, and suppliers that are traditionally held at arms length and, until recently, did not partner with the Air Force. Additionally, as a government agency and military organization, the Air Force operates under a complex set of regulations and instructions, which are established at the highest levels of the United States government. These regulations establish the U.S. Air Force's critical responsibilities for national defense.

1-6 Key Questions:

The overarching questions that established a baseline for this research is:

1. How should the F-16 Avionics Sustainment System be modified to achieve significant performance improvements through lean enterprise transformation?
2. What are the major barriers impeding the system's transformation through the adoption of lean principles?
3. How can these barriers be effectively overcome to derive the benefits of lean transformation?
4. What are the key benefits that can be expected through lean enterprise transformation?

[1] The view of "lean" expressed in the book *Lean Enterprise Value*, Murman et. al. is that of not just eliminating waste, but also the goal of "creating value". This means delivering what customers want and need, as well as satisfying the needs of the other stakeholders in the value stream, including society. The enterprise perspective makes it possible to see the entire value stream as well as interconnected levels of activity that reach across boundaries. In this case study the lean enterprise refers to all stakeholders involved in the efforts to remove failed end-items from aircraft, the end-items repair and the end-item's redistribution after repair back to the flying operations.

However, there are several supporting questions that needed to be answered before a complete answer to the questions above could be provided. These questions and research should be able to be applied to any Air Force or military organization sustainment system in order to transition to a lean enterprise.

- What does the current F-16 Avionics Sustainment System Value Stream look like and where does the most waste in time, effort and money occur; what are the most likely candidates for process improvement?
- What are the current policies at the local (Operating Instructions/Policies), Air Force (Air Force Instructions/Policies), Department of Defense (Policy Directives), and Congressional (Title 10 Mandates) levels influencing the system?
- What are policy constraints affecting a lean transformation from the current value streams? What are some recommendations for changing these policies?
- What, if any, tradeoffs would need to be considered to transition the sustainment system to a lean enterprise?
- What are recommendations for initiating and tracking the implementation of a new value stream map?

1-7 Thesis Overview:

This thesis is organized as follows:

Chapter 2 introduces previous research that broadens the motivation for this thesis by identifying and more fully defining the benefits of transitioning to a lean enterprise. The research covered here was conducted by various organizations for the Air Force sustainment community. This research is not all inclusive, but provides a sound basis for conducting a value stream map of the avionics sustainment system.

Chapter 3 is the core of the research; it contains a current state (January 2003) value stream map (VSM) of the F-16 avionics sustainment system. The chapter divides the current sustainment system into three sections; flight line, base backshop and supply, and depot repair, testing and supply, to provide for a clear indication of where one part of the system or

organization becomes responsible for adding value to the sustainment system. It also provides a typical time line of the flow of end-items through the system by following the Modular Low-Power Radio Frequency (MLPRF) end-item's movement through the system. Each section summarizes how much time each task takes, and whether the task is value added (VA), non-value added but essential (NVAE) or non-value added (NVA).

Chapter 4 identifies the current organizational, financial, information technology, and policy and regulatory influences on the current sustainment system. It provides an overview of how Air Force policies and instructions contribute to these influences, and some of the negative aspects of these influences.

Chapter 5 identifies and addresses enterprise-wide waste in the F-16 avionics sustainment system. It uses the 'seven wastes' identified in the lean thinking literature as a guideline in documenting the various types of waste, to support the overarching conclusions.

Chapter 6 presents the overarching conclusions derived from the value stream mapping task, focusing on both major barriers and sources of waste in the F-16 avionics sustainment system. The conclusions are based on overcoming system-wide waste, enhancing customer focus, improving flow throughout the system, and improving information availability.

Chapter 7 presents recommendations for the sustainment system to become a lean enterprise, and how this may improve the Air Force's workload allocation flexibility under the "50/50 rule". These recommendations reflect Air Force policy changes, the introduction of new "lean" performance measures, system re-organization, and information technology improvements.

Chapter 8 provides a more in depth analysis of the Congressionally-mandated "50/50 rule". It also examines the stakeholder positions on the mandate: U.S. Congress, Public-Sector and Private-Sector. Additionally, an analysis of the effect that properly employed lean principles can have on readiness by examining a past Air Force lean initiative, *lean logistics*. Also, it will provide recommendations for future research that could benefit from the information garnered in the VSM of an Air Force sustainment system.

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Chapter 2: Previous Research

The motivation of this research highlighted in chapter 1 is to help identify barriers and waste that are impeding the transition of the Air Force sustainment system to a lean enterprise. This is further motivated by the Air Force's implementation of Agile Logistics which relies on a responsive sustainment system to reduce supply inventories of end-items and piece-parts. Also, systemic problems that have been identified in previous research provide further motivation for researching new approaches to reducing the sustainment system pipeline time. These studies and supporting research are briefly identified in this chapter. This previous research helps establish the basis for implementing "Lean Thinking" into the F-16 avionics sustainment system that will allow the Air Force to achieve its monetary and mission capability goals, while continuing to improve its support of the F-16 fleet.

There are four previous research studies that have been conducted by different organizations that are pertinent to this research. The first is a white paper generated by the Lean Sustainment Initiative (LSI) at the Massachusetts Institute of Technology (MIT). The white paper titled, Top-Level Characterization of the Air Force Sustainment System Using a Systems Dynamics Model, by James Wolters provides a very high-level overview of the integrated, and highly complex Air Force sustainment system. The second is a report developed by RAND Corporation under Project AIR FORCE in 1988. The report contains information that is consistent with some of the sustainment system problems identified in this research. The report titled, Variability in the Demands for Aircraft Spare Parts: Its Magnitude and Implications, was written by Gordon Crawford. This report identifies reasons why Air Force material managers have trouble predicting end-item demand and part-usage requirements. It provides an important stepping stone to the conclusions as well as recommendations of this research. The third report is from the General Accounting Office (GAO) and is titled, Air Force Supply: Management Actions Create Spare Parts Shortages and Operational Problems. This report further reinforces the RAND report. It also supports this research by providing evidence of problems in the sustainment system that are beyond the scope of this research; however the information is very important for highlighting some of the conclusions described here in Chapter 6. The last supporting research was also conducted under the Lean Sustainment Initiative by Luis Tsuji. The thesis titled, Tradeoffs in Air Force Maintenance: Squadron Size, Inventory Policy, and

Cannibalization, provides more evidence as to the importance of shortening depot repair time. It also uses a model to highlight what effect tradeoffs between squadron size, inventory policy and cannibalization have on aircraft mission capability and aircraft availability.

These four studies represent only a few reasons for the importance of using value stream mapping under the Lean Enterprise analytical framework to shorten depot repair times. They also encourage the greater customer-focus that is inherent in lean thinking and a lean enterprise transformation.

2-1 Top-level Characterization of the Air Force Sustainment System:

This top-level characterization is a white paper released by LSI at MIT in May 2000. Using a Systems Dynamics Model, the author was able to "develop a deeper insight into the causes and consequences of the system's dynamic behavior, so that effective management strategies and methods for achieving significant improvements in overall system performance could be defined". (Wolters, p.3) This initial LSI research categorized the Air Force sustainment system as a Complex, Large-Scale, Integrated, Open System (CLIOS), where a CLIOS is considered "dauntingly complex". (Wolters, p.3) The paper continued to break down how the Air Force sustainment system fit this CLIOS designation: (direct quotes from Wolters, p.3)

- Complex – the Air Force sustainment system consists of a large number of interrelated components (or subsystems).
- Large-Scale – the Air Force sustainment system has a large footprint, and includes factors that are both large in magnitude and long-lived in duration.
- Integrated – the Air Force sustainment system is highly integrated, in that the various subsystems and components within it are closely coupled through feedback loops.
- Open – the Air Force sustainment system is an open system, in that it includes many external factors.

This paper also presented some performance measures of the sustainment system and why this type of research is important to the continued viability of the system. First, is the performance measure, "mission capability", which is used at base-level to determine the availability of aircraft resources on a daily basis. This measure has slipped from 84.6% in 1990

to 74.3% in 1998 for all Air Force aircraft. (Wolters, p.7)[2] Also, the non-mission capable rate due to supply increased from 6.4% in FY90 to 13.9% in FY98. (Wolters, p.9)[1] The measures are similar to what the Air Force is experiencing in 2003 with decreased piece-part inventories, including LRUs, SRUs, and consumable parts, enacting a harmful effect on aircraft mission capability. Another testament to the decline in piece-part inventories is the 78% increase in the Cannibalization Rate between 1995 and 1999. (Wolters, p.12)

The white paper provides a system dynamics model for Logistics, shown in figure 2.1, which describes the movement of material between operational units and repair facilities. This is a different format from the one to be presented in Chapter 3 of this thesis through value stream mapping, but provides another viewpoint of how end-items are brought into and move through depot or commercial repair facilities[3].

Logistics

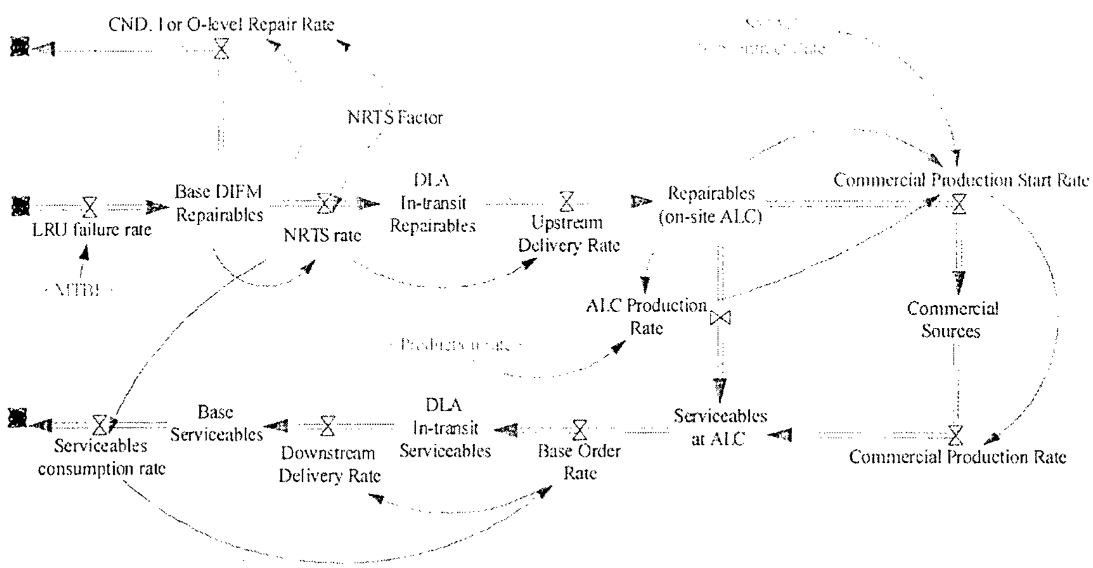


Figure 2.1: System Dynamics Model for Logistics (Wolters, p.15)

Another point addressed is depot funding in another systems dynamics model of the Supply Management Activity Group (SMAG). It mentions that "money unavailability should take into

[2] This data was originally presented by the General Accounting Office in Air Force Supply: Management Actions Create Spare Parts Shortages and Operational Problems, GAO/NSIAD/AIMD-99-77, 1999.

[3] Due to space considerations in this thesis, all the underlying assumptions and detail concerning the system dynamics model presented could not be included. Therefore, for additional information on the development of this system dynamics model, please refer to the LSI White Paper, WP-00-01, Top-level Characterization of the Air Force Sustainment System Using A Systems Dynamics Model by James Wolters, as noted in the Bibliography.

account the SMAG policy of tying Depot Maintenance Activity Group (DMAG) funding to the production rate, instead of the production start rate." (Wolters, p.24) In his footnotes, Wolters says:

> *In essence, the DMAG works with a build-to-order system, but SMAG pays them as if it were a build-to-stock system (where customers purchase finished goods 'off-the-shelf'). As a result, the DMAG suffers from a negative cash conversion cycle. On the other hand, build-to-order companies such as Dell Computer have a positive cash conversion cycle, where payment for each order is provided at production start time; suppliers are paid after production begins and only as component parts are drawn. (Wolters, p.24)*

There are other implications addressed by the establishment of this system, such as "higher MICAP rates at end-of-fiscal years because SMAG could not purchase repair services from DMAG" due to funding constraints. (Wolters, p.24)

2-2 Variability in the Demands for Aircraft Spare Parts:

This RAND report, generated under Project AIR FORCE in January 1988, addressed the variability in the demand process of aircraft spare parts, but more importantly the wide discrepancy between the degree of variability assumed, in requirements modeling, and those actually present. (Crawford, p.1) The report addresses the differences in demand variability causing "reduced confidence in requirements and capability assessment models." (Crawford, p.1) However, more importantly, directly related to this research, is the thought that "pipeline variability, and large, unanticipated pipeline lead times, may directly decrease aircraft availability." (Crawford, p.1)

The report also suggests that "breakdowns" in the repair process (e.g., shortages of EOQ items, SRUs, or repair equipment failures) may cause large increases in unserviceable assets at the depot. (Crawford, p.34) The following pie charts, Figures 2.2 and 2.3, show the division of the top 46, F-15 MICAP end-items across the serviceable inventory, and depot and base unserviceable inventories. Figure 2.2 shows the percentage of items by number of items, while Figure 2.3 shows the percentage of cost of these assets.

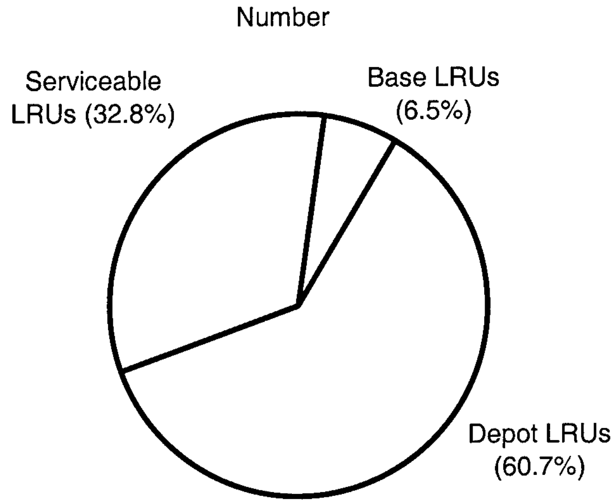
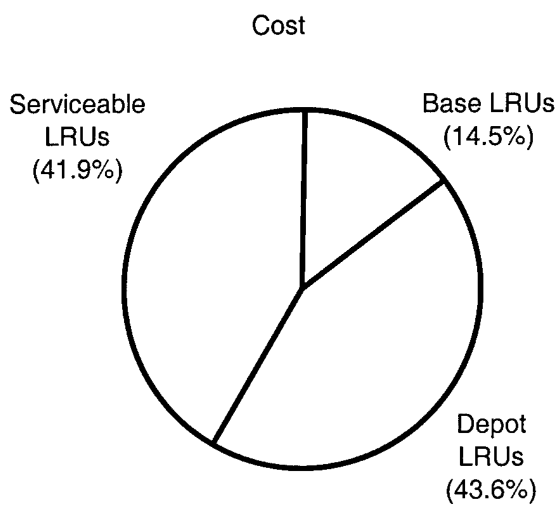


Figure 2.2: Serviceability of components by number, F-15 MICAP (46) (Crawford, p.33)

Figure 2.3: Serviceability of components by cost, F-15 MICAP (46) (Crawford, p.33)



Although this report is 15 years old, it addresses issues that continue to plague the sustainment system to this present day. Namely, the fact that the depot quarterly repair computation, "which is based on a presumed ability to predict needs", contributes to the large number of unserviceable MICAP end-items located at the depot. (Crawford, p.34) Even though the computation of these quarterly requirements takes into consideration a number of variables, it reduces to the following formula: (Crawford, p.34)

Quarterly Repair Requirements = Expected Demands –
Expected Base Repairs – Serviceables

The report suggests a demand prediction model that takes into account that every serviceable asset can possibly result in an increase in aircraft availability. (Crawford, p.34) Therefore, "the procurement philosophy is to rank parts by the ratio of their probable increase of aircraft availability to their cost." (Crawford, p.35) Thereby making those parts with the highest ratio the ones procured, essentially providing the "biggest bang for the buck".

The conclusion of the report is that the "direct effects of pipeline size and variability" cause great difficulty in "computing requirements and assessing capability." (Crawford, p.36) Several of these problems lie in the assumptions made in the forecasting software used by the Air Force, such as inaccurate Variable to Mean Ratios (VTMRs), and a random Poisson arrival rate for end-items into the repair cycle, when it is not necessarily random. The final conclusion is that "depot policies must be reoriented" to reducing repair pipelines and increasing aircraft availability. (Crawford, p.36)

2-3 Management Actions Create Spare Parts Shortages:

This research conducted by the GAO in 1997 and 1998 for the report generated in 1999 examined the effects that spare parts shortages may be having on readiness. Readiness is measured by aircraft mission capability. The research focused on the Supply Management Activity Groups' (SMAG) ability to meet its military customers' needs. "Specifically it discusses (1) the extent and impact of military customers not receiving aircraft spare parts when needed and (2) the reasons why parts were not always available when needed." (GAO 99-77, p.4)

The report provides further background information on the SMAG as a part of the Air Force Working Capital Fund. "This fund relies on sales revenue" (generated from the sale of end-items to customers) "to finance its operations." (GAO 99-77, p.4) Payments received from customers "replenish the cash balance in the fund, which is used to finance ongoing operations, such as purchasing new items or paying for the repair of broken items." (GAO 99-77, p.4) The customers use appropriated funds, usually operations and maintenance appropriations, to purchase these inventory items. (GAO 99-77, p.14) The SMAG is controlled by Air Force Materiel Command, and procures new material and makes repair parts available to customers through inventory control points located at each Air Logistics Center (ALC). (GAO 99-77, p.14)

Although the SMAG continues to operate in the same manner, the Air Force has sought to improve its logistical support of flying operations. In the late 1990s, the Air Force began implementing a new logistical program called Agile Logistics. (GAO 99-77, p.16) The program is an attempt at moving from the old "batch processing" approach of the SMAG determining repair requirements once a quarter to a "repair-on-demand" process where repair decisions are made on a daily basis. (GAO 99-77, p.16) This new program is meant to encourage increased cooperation between the SMAG and Depot Maintenance Activity Group (DMAG). The DMAG includes the shops that actually repair the end-items turned-in by and requested by operations, but has a direct customer relationship with the SMAG for funding purposes. The result of this cooperation is that the DMAG will only repair end-items that have been requisitioned by the operational customers. (GAO 99-77, p.16) The Air Force plans to use the Agile Logistics program to "(1) reduce the time required to repair inventory items, (2) reduce inventory levels, (3) match the repair of items with the demand from customers, and (4) rapidly move items to and from customers. (GAO 99-77, p.16)

Performance measures used to monitor the performance of the SMAG indicate a negative trend in its ability to meet customer needs. The data indicates that "increased instances of (1) aircraft not being mission capable, primarily due to supply problems, (2) usable parts being removed from one aircraft to keep others mission capable, and (3) mobility readiness spares package assets being used to keep aircraft mission capable." (GAO 99-77, p.20) These are good indicators that SMAG is not meeting customer needs. In fact, mission capability rate for all major aircraft has declined from 84.6% in 1990 to 74.3% in 1998. (GAO 99-77, p.21) In addition, the total not mission capable due to supply rates have more than doubled for Air Force major aircraft from 6.4% in 1990 to 13.9% in 1998. (GAO 99-77, p.22) Another indicator of the SMAG not meeting customers' part needs is the significant rise in cannibalization rates.

The action of removing serviceable items from one aircraft to be placed on another is referred to as cannibalization. Flight line maintenance units conduct cannibalization when spare parts are not in the supply system, and there is pressure to generate a mission capable aircraft. Cannibalization is measured as the "average number of cannibalization actions per 100 sorties flown." (GAO 99-77, p.22) The GAO report presents cannibalization rates for three major Air Force aircraft; the F-16, B-1 and C-5. Since it is the focus of this research, the F-16 cannibalization rate is of particular interest. From 1993 to 1998 the cannibalization rate for the

F-16 fleet has increased from 5.3 to 12.1 per 100 sorties flown. (GAO 99-77, p.23) This is further proof of SMAG's inability to provide the needed spare parts to the units that need them most.

Final proof of the SMAG's failure to identify the proper amounts of required spare parts for its customers is the fact that operational units are using mobility readiness spares package (RSP) assets to satisfy peacetime critical parts shortages. (GAO 99-77, p.24) RSPs are air transportable packages of repair parts meant to be used only during contingencies to help compensate for operational surges and extension of the supply system during those times. (GAO 99-77, p.24) In addition, the effectiveness of the SMAG is measured by its supply issue effectiveness rate, which is the "percent of time that base supply will have a part in stock when a maintenance organization needs the part for repairing an aircraft." (GAO 99-77, p.25) The supply issue effectiveness rate aggregates both consumable and reparable items into its calculus. This provides a supply issue effectiveness rate that from 1994 to 1998 declined from 74.9% to 71.6% respectively. (GAO 99-77, p.25) However, when just considering reparable items, the issue effectiveness rate becomes 49.3% and 48.7% in fiscal years 1997 and 1998 respectively. (GAO 99-77, p.26) This demonstrates that at least 50% of the time a repairable end-item is requested by the customer, a serviceable unit it is not available for use.

There were three reasons presented for SMAG's failures in meeting customer demands; (1) "inventory requirements forecasting and budget problems", (2) "overly optimistic Agile Logistics goals", and (3) "untimely repair of end-items". (GAO 99-77, p.30, 33, 36) Untimely repair means that end-items are taking considerably longer to repair than projected by the Air Force for budgetary and requirements determinations.

The GAO reviewed the status of 155 items during their two-year study of these three weapon systems. Of those 155, 57 were found to have problems that were a direct result of the SMAG's ability to properly forecast inventory requirements to meet its customers' needs. (GAO 99-77, p.30) They were unable to meet customer needs because inventory requirements had been understated by 18% in September 1997. (GAO 99-77, p.30) The first cause of this underestimation was that the SMAG only "received $2.5 billion in fiscal year 1997 obligation authority even though inventory requirements were estimated to be $3 billion." (GAO 99-77, p.31) The second cause for the inability to meet customer needs was because "the SMAG's inventory requirements increased by about $300 million between March 1995, when they

initially determined their fiscal year 1997 inventory requirements, and March 1996 when the Air Force updated its inventory requirements." (GAO 99-77, p.31) In order to make up for the differences in the budget and funds received, the "SMAG attempted to optimize their obligation authority by directing DMAG activities to accomplish the following three actions." (GAO 99-77, p.31) They were (1) "to repair only the highest priority items, such as MICAPs", (2) "repair items as needed to avoid repairing unneeded items", and (3) "limit the procurement of new items and further rely on the repair of items and focus on procuring the piece-parts needed to accomplish these repairs." (GAO 99-77, p.31) By focusing only on high-priority items, low-priority items, such as base stock levels, suffered and later would most likely introduce more high-priority items into the repair system. (GAO 99-77, p.32)

The second reason the GAO found to be a cause for not meeting customer demand were "overly optimistic Agile Logistics goals." (GAO 99-77, p.33) For 31 of the 155 items, problems were caused by inventory management's inability to achieve the goal of reduced processing time. (GAO 99-77, p.33) By not achieving these goals the SMAG had less funding than required to meet customer demand. (GAO 99-77, p.34) "For example, one ALC indicated that the total pipeline time for the items it managed was about 68 days during fiscal year 1998 (compared to a standard of 52 days)." (GAO 99-77, p.34) Furthermore, AFMC headquarters determined that the average time for reparable items in the Command was 44.7 days, which was considerably less than the budgeted goal of 9 days. (GAO 99-77, p.34) The leadership at Air Force headquarters also acknowledged that this untimely processing of reparable items adversely affected aircraft mission capability. (GAO 99-77, p.35) The reason that was given for the large differences in budgeted versus actual processing times was that DoD policy did not allow them to consider AWP and backorder times when determining funding requirements. (GAO 99-77, p.35) Both Air Force and DoD officials acknowledged that AWP and backorder problems were indications that the supply system was not working properly. (GAO 99-77, p.35) However, they are against purchasing inventory to support the longer processing time in fear that the inventory would become excessive when the root causes of the extended processing times was identified and corrected. (GAO 99-77, p.35)

Finally, the introduction of the Air Force's Agile Logistics program reduced inventory levels even further in anticipation of shorter processing times. Thereby, with inventories reduced and processing times not reduced, a conflict occurred which further aggravated the parts shortage and

untimely repair of items. (GAO 99-77, p.36) They identified that the most frequent cause of untimely repair was shortages in piece-parts, and the entering of these items in AWP inventories. (GAO 99-77, p.37) The AWP problem adversely affected the SMAG's ability to support its customers because it increased the number of broken items in the sustainment system, and limited the number of serviceable items that could be provided to customers. (GAO 99-77, p.37) The Air Force has conducted its own studies of the AWP problem, but has done little to resolve the issue. (GAO 99-77, p.38) The GAO identified three tasks that needed to be accomplished before the Air Force could begin to solve this problem. These tasks are (1) "developing a long-term strategy for identifying and correcting the root cause(s) of the AWP problem, (2) a systematic process for identifying and focusing management attention on the most critical AWP problem items, or (3) a standardized approach that item managers can use to analyze data on AWP problems." (GAO 99-77, p.38) AFMC officials stated that AWP problems were partly due to the lack of reliable data on the parts causing AWP problems. (GAO 99-77, p.38) In addition, data on the number of items in AWP, and parts required to repair them must be obtained from several different sources, some of which are "not available in automated format." (GAO 99-77, p.38)

The GAO concluded the report with commenting on the Air Force's and DoD's comments on their findings. The DoD agreed that there were shortfalls in the Agile Logistics program, but that it has helped the Air Force reduce the supply pipeline time from 67 to 52 days from 1994 to 1998. (GAO 99-77, p.41) The Air Force therefore based its 1998 budget on the 52 day average pipeline time. However, the data gathered by the GAO "indicated that SMAG's average pipeline time for the fourth quarter of fiscal year 1998 was 87.5 days." (GAO 99-77, p.42) Again this was due largely to the shortage of piece-parts, and that AWP and backorders accounted for 37.1 of the 87.5 days an item spends in the pipeline. (GAO 99-77, p.42)

This GAO report clearly indicates the adverse affect that AWP and extended repair times have on the Air Force's sustainment system. They also demonstrated the problems that the SMAG was having in predicting its customer's needs, as well as meeting these needs in a timely manner. Overall these problems severely impact aircraft mission capability and the meeting of operational requirements for aircraft, such as recurring pilot training.

2-4 Tradeoffs in Air Force Maintenance:

The Air Force is attempting to improve maintenance performance in an effort to improve aircraft mission capability. Attempts to improve the maintenance system in a piecemeal fashion have resulted in unintended consequences and global sub-optimization. (Tsuji, p.17) Therefore, a high-level simulation model was developed to "illustrate critical tradeoffs and provide a valuable tool for learning and improving system performance in the future." (Tsuji, p.17) "This thesis used a simple high-level simulation model to model the sustainment of a unit of C-5 cargo aircraft." (Tsuji, Abstract) "It examines high-level tradeoffs in performance and cost due to the number of aircraft, spare parts and cannibalization policies." (Tsuji, Abstract) The effects of depot repair time are also considered and their effect on the sustainment system. (Tsuji, Abstract) The thesis also provides a fairly high-level overview of the sustainment system as observed through a series of familiarization visits by LSI members to various Air Force facilities.

The high-level tradeoff modeling was completed with RAND Corporation's Dyna-METRIC modeling software. "Dyna-METRIC models the Air Force maintenance system and evaluates wartime readiness and sustainability based on logistics resources and pipelines." (Tsuji, p.44) The model is flexible and can accommodate many variables and scenarios. "It has been used to evaluate two-level (2LM) versus three-level maintenance (3LM) as well as several other management practices and structures." (Tsuji, p.44) The modeling conducted in this thesis was based upon three main cannibalization scenarios; (1) no cannibalization, (2) using one "cann-bird", cannibalized aircraft, and (3) unrestricted cannibalization. (Tsuji, p.44)

In the no cannibalization scenario, it was determined that increasing the number of aircraft does not have as large an impact on percentage of requested flights that could be flown as an increase in spare parts. (Tsuji, p.68) The initial parameters were 10 aircraft and 8 spares. If aircraft are increased by 50% to 15 aircraft and spares are kept constant at 8, the percentage of requested flights the wing is able to fly increases by 13%. (Tsuji, p.68) However, in the case that spares are increased by 50% to 12 spares and aircraft are kept constant at 10, the percentage of requested flights increases by 34%. (Tsuji, p.68) Therefore, there is greater impact on the percentage of requested flights available by adding spares, rather than adding aircraft to the squadron. This makes sense from the fact that excess aircraft will only allow more flights to be flown, but the additional aircraft will eventually fail as well, adding to the total number of failed parts and deepen stock-outs. (Tsuji, p.68) However, an additional set of spares could be used to

repair several aircraft, and will decrease the probability of stock-out for each of the parts. (Tsuji, p.68) This is where the tradeoff, aircraft or spares, must be made because the Air Force needs to operate under opposing expectations. On one hand, "the Air Force is expected to be efficient and lean during peacetime (less spares), so as not to waste taxpayers' money, and on the other, it is also expected to be able to surge to meet necessary capacity during wartime (more spares)." (Tsuji, p.70)

The figures below demonstrate the effects that tradeoffs in aircraft and spares have on the percentage of flights, Figure 2.4, and mission capable rate, Figure 2.5. It is evident that when the number of planes is increased from 10 to 15, in the case of the model, the percent of flights increases from 70 to 79 percent, if you hold the amount of spares constant at eight. However, if spares are increased from 8 to 12, with the continued 10 aircraft, the percent of flights increases from 70 to about 93 percent. The same increase is also evident in mission capable rate increases for the same scenario. However, both rely heavily on the initial spare parts availability, since increases in spares experience a diminishing marginal utility.

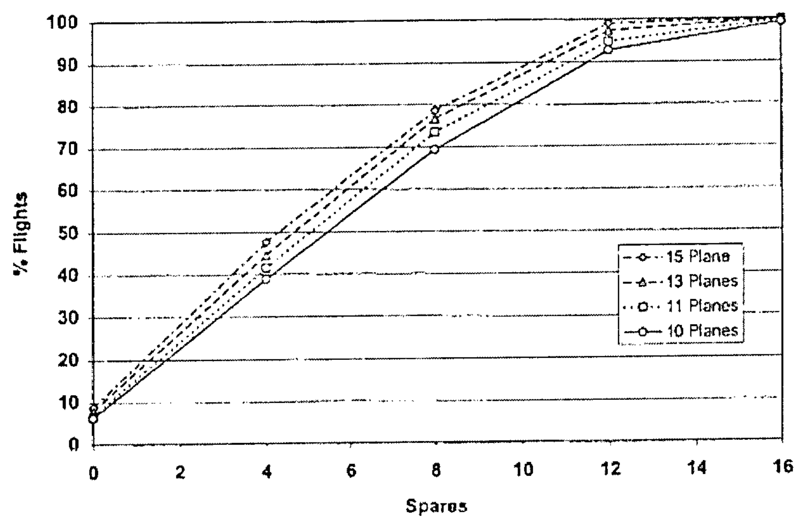


Figure 2.4: Percent of Requested Flights Flown, no cannibalization (Tsuji, p.71)

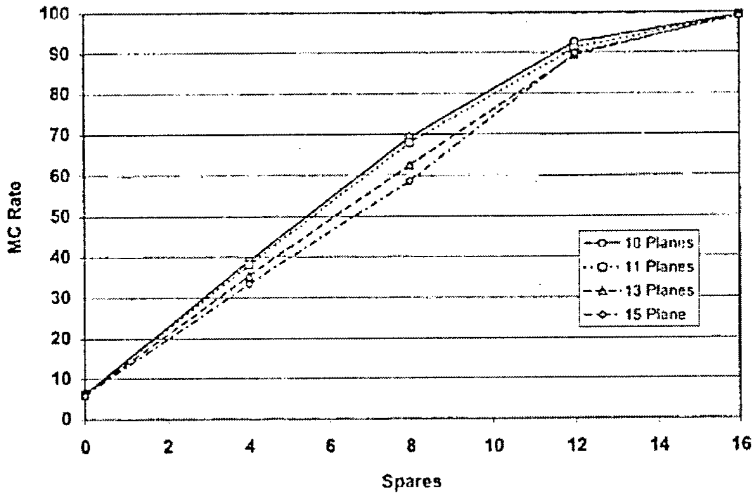


Figure 2.5: Mission Capable Rate, no cannibalization (Tsuji, p.71)

In the initial modeling of the tradeoffs of aircraft, spares and cannibalization depot repair time was held constant at 50 days, and was not considered in the impact of the three cannibalization policies. (Tsuji, p.85) However, "the depot repair time coupled with the parts' probability of failure should establish an effective stock level for spares." (Tsuji, p.85) Therefore, a "shorter repair time requires a smaller buffer inventory of spares" to cover this time. (Tsuji, p.85) The following figures show the effects that different depot repair times have on the percentage of requested missions flown, Figure 2.6, and mission capability rate and number of mission capable aircraft, Figure 2.7, assuming one "cann-bird" and 15 aircraft. The results show a strong impact due to repair time.

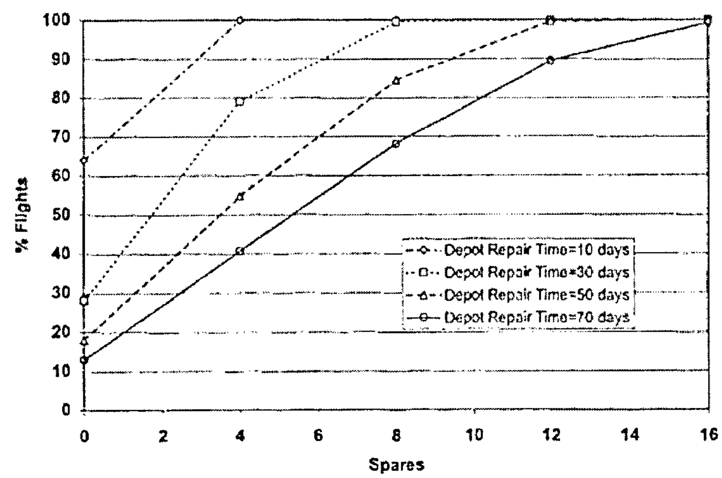


Figure 2.6: Percent of requested missions flown resulting from different repair times, for 15 aircraft, using one "cann-bird". (Tsuji, p.87)

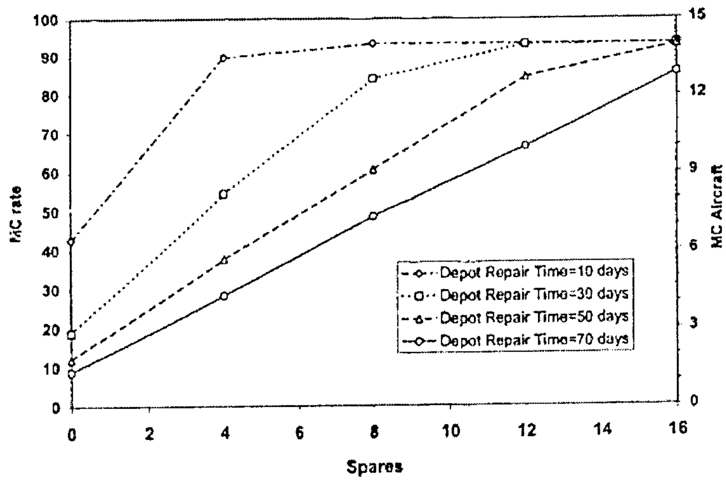


Figure 2.7: Mission Capable rate and number of Mission Capable aircraft resulting from different repair times, for 15 aircraft, using one "cann-bird". (Tsuji, p.88)

There are several other graphs presented in the Tsuji thesis showing the effect depot repair time has on the percentage of requested flights flown, mission capability rate, and number of mission capable aircraft. Data extrapolated from Figure 2.6 shows how changing repair time from 50 to 30 days can increase the percentage of requested flights flown from 55 to 79 percent in the case of four spares. As demonstrated by an earlier graph, as the number of spares increases there is a diminishing marginal utility. However, the decrease or increase in repair time can have dramatic effects on the readiness of the aircraft fleet. This previous research and modeling illustrates the huge potential that reducing depot repair time has on aircraft readiness, and smaller required investment in spare parts. In addition, Figure 2.8 illustrates that "as repair time decreased, the amount of cannibalization also decreased for higher spares levels." (Tsuji, p.86) "This occurs because as repair time decreases, the existing spares level is able to more adequately cover demands, resulting in fewer cannibalizations." (Tsuji, p.86)

This model based most of its cost assumptions off the value of the aircraft being analyzed, the C-5 Galaxy. The approximate cost of the aircraft was $185 million, in constant 1996 dollars, and the cost of the spares is not readily available, so the value was varied to study the effect cost has on the tradeoffs. (Tsuji, p.94) A holding cost of 10% per year was assumed for the assumed capital cost of spares. (Tsuji, p.94) The model also had to value the case of "missed flights" from non-mission capable aircraft, since the C-5 is a transport aircraft. This value was

determined to be $125,000, which is half the loss of revenue from not flying a mission because the mission is typically flown as soon as possible. (Tsuji, p.94) Another cost input into the

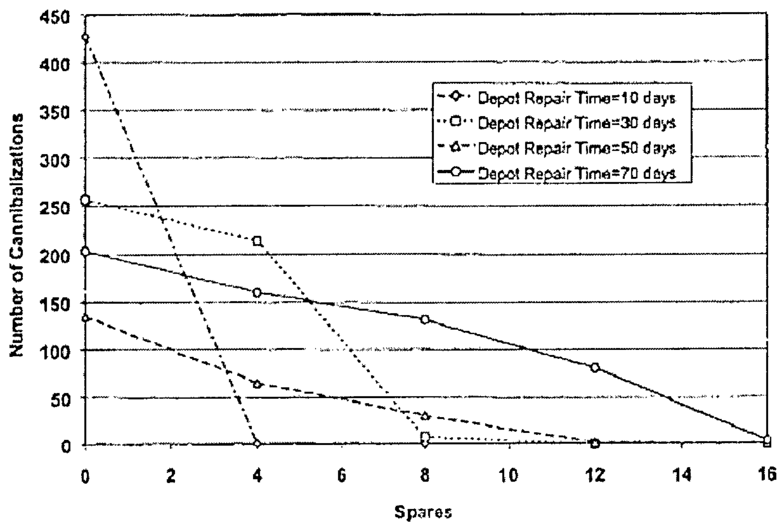


Figure 2.8: Number of cannibalizations resulting from different repair times, for 15 aircraft, using one "cann-bird". (Tsuji, p.89)

model is the cost of cannibalization. Through extrapolation (with the uncertainties inherent in the system), the cost per cannibalization was determined to be $136 per occurrence. (Tsuji, p.95) Figure 2.9 shows the cost effective amount of spares, based on the assumptions with 15 aircraft, to have with various depot repair times. The shorter the repair time, the fewer required spares, the more cost effective the system.

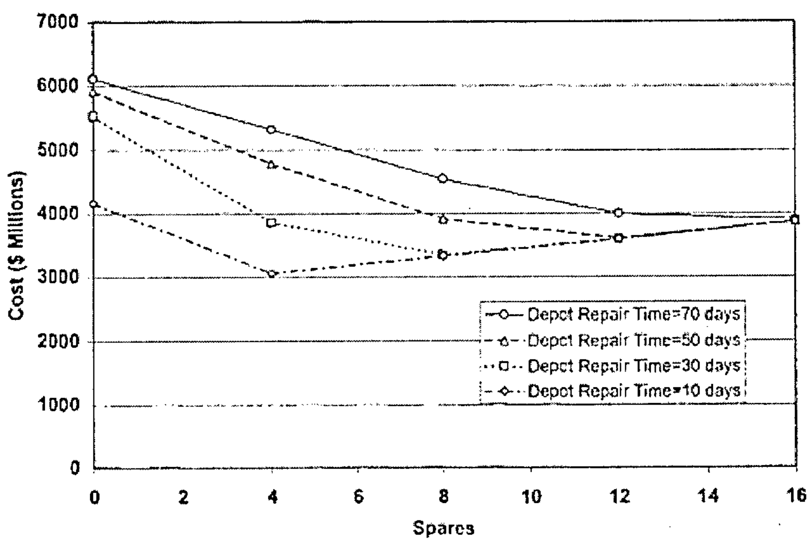


Figure 2.9: Cost for different Depot Repair Times, with 15 aircraft (Tsuji, p.101)

"The key point of this thesis is that it is important to consider the systemic effects of decisions and changes in the Air Force." (Tsuji, p.109) "Making decisions that seem to be beneficial on a local scale may in fact be detrimental to the overall system." (Tsuji, p.110) It is important to understand the behavior of the Air Force sustainment system and the tradeoffs between such factors as the number of aircraft, number of spare parts, and cannibalization. (Tsuji, p.110)

2-5 Summary of Previous Research:

There are three key determinations made by the previous research reviewed in this chapter. First is the fact that the Air Force sustainment system is highly integrated, and a positive change in one part of the system could negatively impact another part of the system. Likewise, a positive change in one part may very likely facilitate a positive change in another part of the system. Second is the adverse affect that not meeting customer demand has on aircraft mission capability. This is further aggravated by the assumptions made by the SMAG in its inventory requirements forecasting and the overall DoD budgeting process. The final determination is that parts availability and the length of time that items remain in the sustainment system has considerable impact on aircraft availability and mission capability. These points will be considered in the value stream mapping of the F-16 avionics sustainment system, as we seek to provide recommendations. By employing lean thinking principles to the value stream map, some of the root causes of these problems can be identified and addressed to improve the Air Force sustainment system.

Chapter 3: Current Value Stream Map

3-1 Overview:

The F-16 Avionics Sustainment System is a closed loop system of avionics flowing from the flight line aircraft maintenance units to base backshops and supply to depot supply, repair and testing, and finally redistribution back to the flight line. Therefore, what one part of system does to optimize its local operations affects the entire system in some manner. This system is extremely large both in the number of items handled and number of aircraft it supports, but also in the fact that it is world-wide and at times is extended to remote regions with little more than a runway, and avionics is just one part of sustainment.

Every person involved in the system is dedicated to the overall mission of keeping aircraft flying and mission capability at its highest levels. However, at times they are limited by organizational, financial, informational, and policy and regulatory constraints. This chapter will outline the current state of the F-16 Avionics Sustainment System by separating the Value Stream Map (VSM) into three sections. First is flight line aircraft repair and supply support. The second section is base backshop end-item repair and testing and base supply. The final section is depot end-item repair, testing, and supply.

The sustainment system can be thought of on a much more basic level as shown in Figure 3.1. It is viewed as only two sections, base repair and depot repair by the material managers, which oversee exactly how many end-items and piece-parts are in the sustainment system. The simple diagram neglects the important role of supply and transportation in the sustainment system, but it is implicitly understood that supply is an important part of aircraft sustainment.

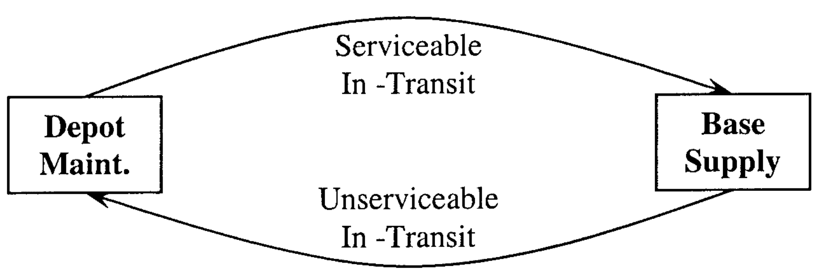


Figure 3.1: Generalized Closed-Loop Avionics Sustainment System

There are two overarching philosophies of the sustainment system. One philosophy is, that of the flight line and base level, to keep as many aircraft fully mission capable by all means

available. This is demonstrated in the Aircraft Maintenance Unit VSM, flight line maintenance operations, by the inclusion of the several tracks the unit takes to complete an on-aircraft repair. Also, the base backshops share the same philosophy, and work closely with flight line maintenance to achieve mission capability goals.

The second philosophy is repairing end-items within the financial, organizational, and regulatory constraints established by the Department of Defense, Air Force and Air Force Materiel Command. This is demonstrated in the depot repair, testing and supply VSM where end-items are inducted when the need arises based on quarterly negotiated quantities, and, on occasion, to satisfy priority one backorders (MICAPs) that are keeping aircraft from being mission capable. However, the most binding of these constraints, financial, dictates exactly how many end-items are repaired in a quarter, and how many spare or piece parts can be kept in on-hand inventories to minimize inventory holding costs. In instances where parts are not available, man-hours are lost placing items in awaiting parts (AWP) inventory, as well as man-hours expended being tied-up in an unserviceable end-item. On the other hand, the pressing need to meet efficiency standards can cause the shops to over-produce easy to repair items that do have parts available and under-produce those with parts supportability problems.

The Value Stream Maps, contained within, were generated during a visit to the 388th Fighter Wing and Ogden Air Logistics Center, both located at Hill Air Force Base, Utah. These VSMs are very detailed in order to demonstrate the status quo that will be addressed to eliminate possible waste (muda in the lean jargon), and create value by enhancing the "flow" of end-items through the sustainment system. First, the VSM is described in text and graphics, then tables outlining the time each task takes to be accomplished supports this text. The tables also label each task as; (1) Value Added (VA), meaning some value is being added to the sustainment system and/or end-item; (2) Non-Value Added (NVA), meaning no value is gained by accomplishing the task; and (3) Non-Value Added but Essential (NVAE), meaning no value is added to the system or end-item, but is essential to the sustainment process.

It is assumed in the VSM exercise that parts are available to establish a baseline of task time required to complete the closed-loop sustainment system. In cases, such as the MLPRF, there has been considerable difficulty in keeping the required Shop Replaceable Units (SRUs) in stock that most typically fail. Therefore, a majority of the end-items that require these SRUs are placed in an awaiting parts (AWP) inventory until serviceable parts are acquired. This causes the

task time line associated with the AWP inventory to vary greatly depending on the receipt of backordered SRUs. This in itself is a wasteful exercise of waiting, and rework caused by placing end-items in AWP, and will be explained further this chapter.

3-2 Aircraft Maintenance Units:

The Aircraft Maintenance Unit (AMU) is responsible for servicing, inspecting, maintaining, launching and recovering, meeting upon landing, assigned aircraft, and ensures all mobility requirements are met as stated by Air Force Instruction (AFI) 21-101. AMUs are typically referred to as flight line maintenance, which is only a part of the unit's responsibility. The mobility requirements include mission readiness kits for each aircraft, as well as ensuring personnel are trained and prepared for scheduled and unscheduled deployments. 21-101 designates an AMU for each assigned operations squadron (OS). The AMU consists of the following sections: Aircraft, Specialist, Scheduling, Weapons, Debrief and Support. The pertinent areas to the sustainment system will be further explained in the organizational section of Flight Line AMUs in Chapter 3.

3-2-1 AMU Value Stream Map Processes:

The Value Stream Map (VSM) for avionics end-items begins when troubleshooting procedures fail to correct discrepancies with the Master Fault List (MFL) that is generated by the F-16's self-diagnostic system. Troubleshooting is justified when an aircraft returns from a mission with a system failure or other discrepancies. Some of these discrepancies are self-correcting by cycling aircraft power or cannot be repeated because it was an in-flight anomaly. In cases such as these, the discrepancy is documented and will be checked the next time that the aircraft flies to determine whether there are actual system problems or it was a one-time occurrence.

Using the MFL codes generated by the aircraft, the crew chief and/or avionics specialist is able to determine fairly accurately which avionics system is failing. In most cases the failure is in an avionics Line Replaceable Unit (LRU), which is considered an end-item, and requires the LRU to be removed from the aircraft and replaced with a refurbished unit from the serviceable end-item inventory. Before removal, as shown in figure 3.2, the avionics specialist, responsible for the removal and replacement of avionics items, conducts a supply inquiry to determine if

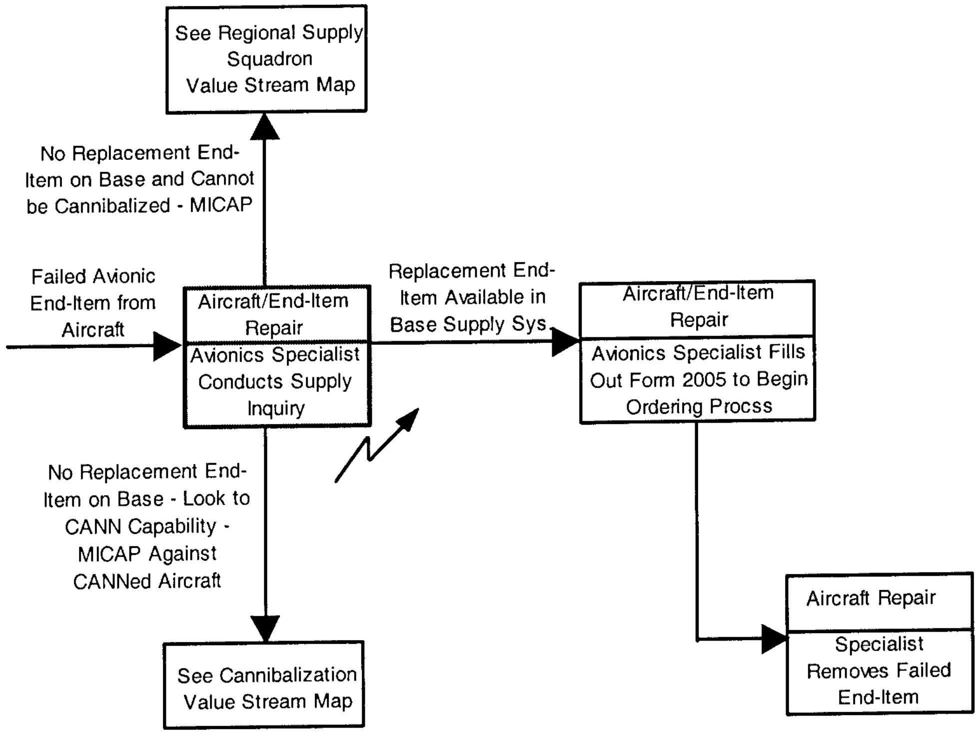


Figure 3.2: Avionics Specialist's Supply Inquiry

any serviceable end-items are available. In some cases there are no serviceable end-items in local supply sources, so additional actions need to be taken to acquire a serviceable unit. One option to acquire a serviceable end-item is to cannibalize it from an already non-mission capable aircraft. The second is to query the regional supply system for possible serviceable end-items at other inventory locations.

If a serviceable item is available locally, the specialist submits an order request form, Form 2005, to begin the supply process of pulling the item from base supply as demonstrated by figure 3.3. The flight line supply support personnel accept the order request form from the avionics specialist before they attempt to acquire a replacement end-item. If the item is coming from local sources of supply then they will work directly with base supply to get the replacement end-item to the flight line as soon as possible. The serviceable item may be pulled from benchstock, which is stored close to the flight line, from base warehouses or from mission readiness kits stored in base supply. The time it takes to retrieve the item depends on its location. If it is in benchstock for instance, it could take as little as five minutes to acquire the serviceable end-item,

and if it is in a base warehouse, it could take as much as an hour to get the item depending on base supply's manpower availability.

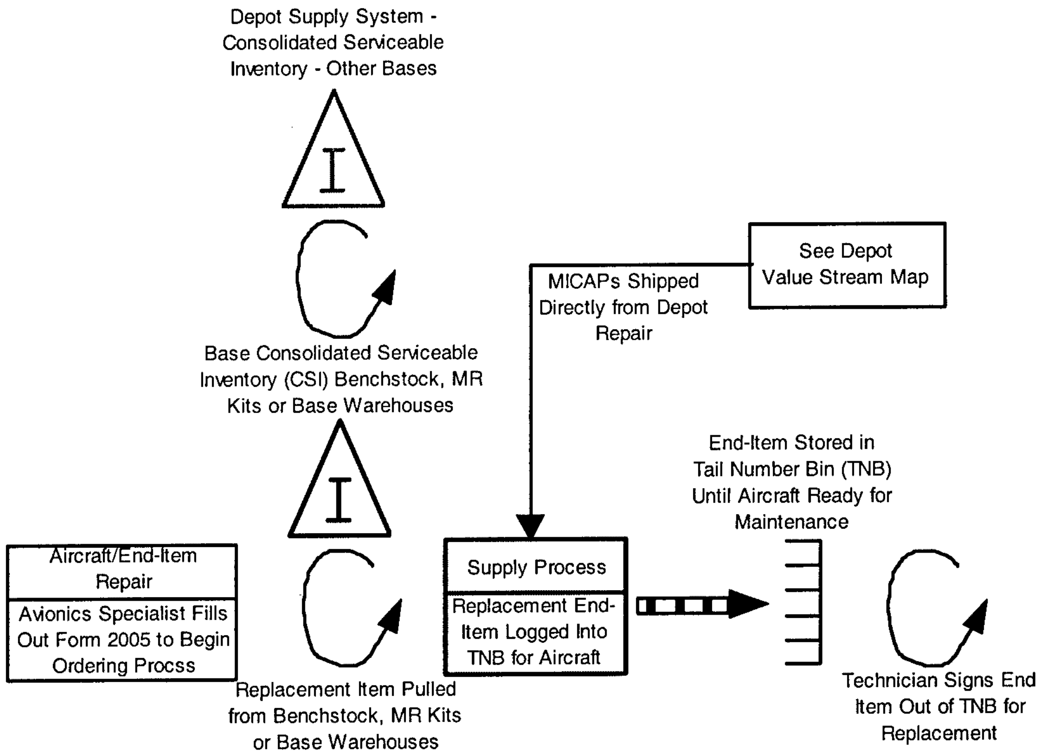


Figure 3.3: Supply's Acquisition and Avionics Specialist's Receipt of Serviceable End-Item

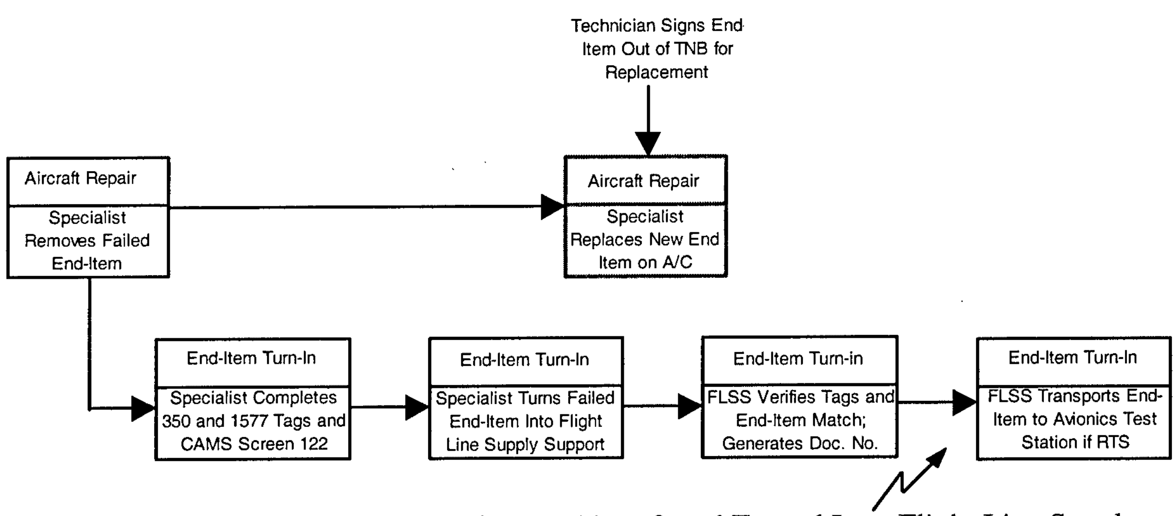


Figure 3.4: Failed End-Item Removed From Aircraft and Turned In to Flight Line Supply

Figure 3.4 outlines the parallel nature of the avionics specialist removing the failed end-item from the aircraft while awaiting the replacement end-item. The specialist then turns-in the failed component with completed failure description tags and Consolidated Aircraft Maintenance

System (CAMS) screen 122 printout for documentation of the end-item's removal from the aircraft. At the same time, the specialist signs out the replacement end-item from the aircraft tail number bin (TNB).

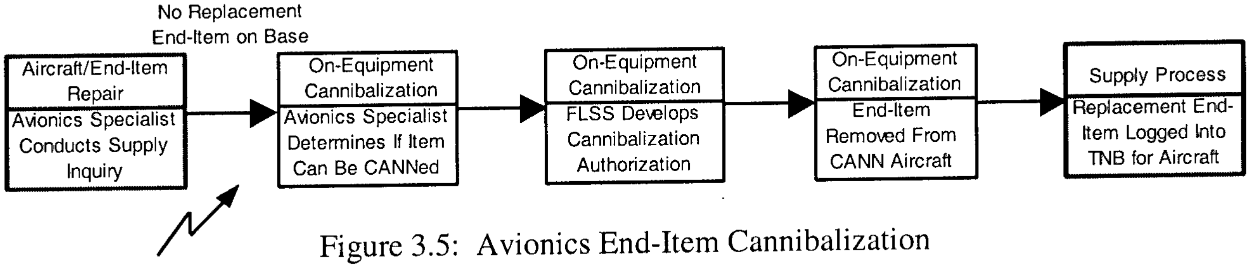


Figure 3.5: Avionics End-Item Cannibalization

If the item needs to be cannibalized from another aircraft, supply support coordinates the cannibalization (CANN) efforts, as shown in figure 3.5 above, with the production supervisor and the maintenance unit that conducts the cannibalization of the replacement item. This is typically referred to as a "convenience CANN", since it allows the unit to quickly fix one of two aircraft. Once the item is removed from the CANN aircraft, it is brought to the flight line supply support to be logged into the TNB. In some cases a replacement item will not be able to be cannibalized because of lack of availability or inability to be CANNed. This requires flight line supply support to develop a MICAP requisition with the Regional Supply Squadron (RSS). The RSS checks other bases and distribution facilities for serviceable replacement items. If an item is found, it is shipped to the requesting aircraft maintenance unit. This process is briefly outlined in figure 3.6. This action is considered after cannibalization because it is easier for the AMU to continue to work an aircraft that already has personnel and ground support equipment connected, rather than disconnecting the equipment and reassigning personnel, only to need to reassign them later when the part arrives in the next day or two.

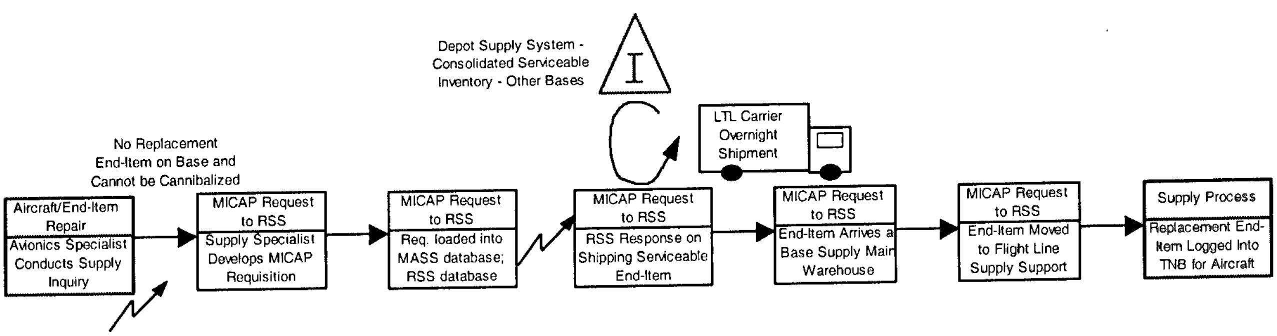


Figure 3.6: MICAP Request to Regional Supply Squadron

Once the replacement item is checked out of the TNB by the avionics specialist, the specialist places the new end-item on the aircraft, accomplishes operations checks to ensure the new end-item corrected the failure, and then completes the aircraft forms and CAMS to reflect the type of repair, as figure 3.7 shows. The aircraft is then returned to full- or partial- mission capability depending on other repairs or discrepancies.

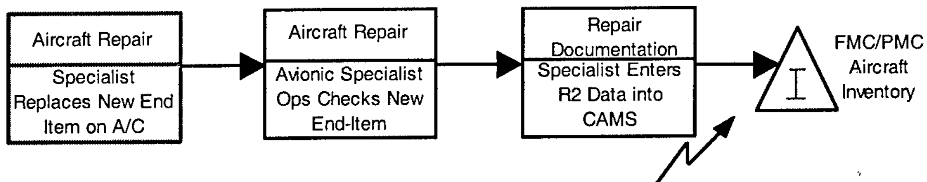


Figure 3.7: Aircraft Returned to Full or Partial Mission Capability

While the above process has outlined what is accomplished to acquire a replacement end-item from the supply system, the turn in of the removed, failed end-item takes a much longer and involved process. This process also goes beyond the AMU to base backshops and supply and eventually to depot testing, repair and supply.

The avionics sustainment system truly begins once a failed LRU, or end-item, is turned in to flight line supply support by the avionics specialist, shown in figure 3.4 above. Flight line supply support verifies the completion of documentation by the specialist and matches it with the end-item being turned in. In many instances the specialists completes all documentation once the repair is complete, which makes matching the documentation especially important. Upon verification of all discrepancy tags and forms, the supply support specialist generates a document number, which makes the end-item a Due-In-From-Maintenance (DIFM) item. This DIFM status drives the flight line supply support personnel to turn-in the end-item for credit. However, there are two different processes, shown in figure 3.8, that determine where the item goes from the flight line depending on if the item is Reparable-This-Station (RTS) or Not-RTS (NRTS). If an end-item is considered RTS, then flight line supply support transports the item to the local Avionics Test Station (ATS), or backshop, for further testing and repair attempts. However, if the item is NRTS, it is transported to base supply for immediate shipment to its respective depot repair facility.

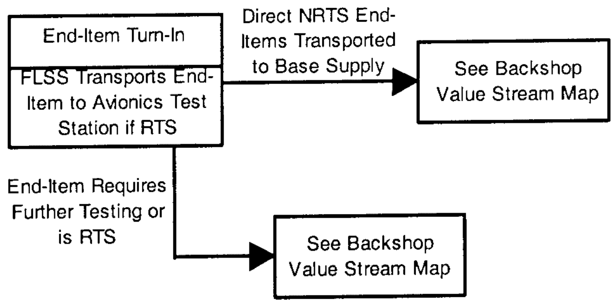


Figure 3.8: End-Items Moved From Flight Line to Base Supply or Repair

For this case study, the Modular Low-Power Radio Frequency (MLPRF) end-item will be our focus. This is a RTS end-item; therefore, its VSM takes it through the ATS, which is explained in more detail in the backshop section of this chapter. The following tables outline the time each task takes in the AMU and FLSS sections of the VSM. It also labels each task as VA, NVA, and NVAE as explained in section 3.1 of this chapter.

Table 3.1: Avionics Specialist VSM Time Line

Action	**Time to Accomplish**	**Cumulative Time**	**VA, NVA or NVAE**
1. If failure – Remove/Replace (R2) end-item (LRU).			
1a. Supply Inquiry – submit part number (NSN) to supply to determine if any end-item replacements available in stock → Avionics Specialist self-inquiry or support assistance in locating serviceable end-item	10 min walk to supply support 3 min	10 min 13 min	NVA VA
1b. If in stock – avionics specialist fills out Form 2005 to order part from supply	2 min	15 min	NVAE
1c. Supply Process – See VSM for Flight Line Supply Support	25 min	40 min	VA
1d. Remove failed end-item from aircraft assuming awaiting new end-item arrival in flight line supply support	20 min (MLPRF)	60 min	VA
1e. Replace new end-item from supply on aircraft	20 min (MLPRF)	80 min	VA
2. Operations check on aircraft Assuming AGE support equipment in place – usually not a problem if ordered before removing failed end-item	60 min	140 min	NVAE
3. Enter R2 data into CAMS computer system	30 min	170 min	NVAE

for tracking of repair data → Fill out tags (350 and 1577) for failed end-item turn-in to Avionics Test Station (ATS) → Print Screen 122 from CAMS for job number to give to ATS			

Table 3.2: Flight Line Supply Support (FLSS) VSM Time Line

Action	**Time to Accomplish**	**Cumulative Time**	**VA, NVA or NVAE**
1. Inquiry initiated by Avionics Specialist (AMU) by submitting Form 2005 → Using pre-designated number, the specialist is provided a document number for the order request by the supply technician to track end-item requisition	See 1a Above	-	-
2. Supply technician conducts Standard Base Supply System (SBSS) inquiry to check base warehouse stocks, Mission Readiness (MR) Kits and Benchstock Supply for Replacement End-items	2 min	2 min	NVAE
3. Time to Acquire Replacement End-item depends on the parts location (e.g., benchstock, base warehouse, depot, etc.). Also, supply technician looks for possible cannibalization options if necessary			
If End-item Located in Base Supply: 3a. End-item located in central base warehouse away from flight line - or End-item located in MR Kit of flight line warehouse (typical for avionics items assuming sustainment system operating efficiently) - or End-item located in flight line supply support benchstock -	60-80 min 10-15 min 5 min	62 min 17 min 7 min	 VA
It End-item not in Base Supply, but can be Cannibalized (CANNed): 3b. Supply Technician contacts CANN Dock counterpart to determine if end-item can be CANNed -	5 min	7 min	NVA
If End-item can be CANNed from CANN or			

Phase Aircraft: 3c. Supply Technician develops CANN authorization paperwork and initiates MICAP requisition against CANN aircraft instead of original aircraft (See CANN VSM) - → Supply Technician coordinates CANN actions with Production Supervisor (Pro Super) for Approval based on Flying Schedule and Requirements → If Pro Super concurs then Paperwork completed so the "serviceable" item can be removed from CANN Aircraft	20 min	27 min	NVA
If End-item Not in Base Supply and Cannot be CANNed: 3d. Supply Specialist develops MICAP requisition against original aircraft - → Occurs only after all base resources are checked for availability	10-15 min	17 min	NVA
3e. MICAP requisition loaded into MICAP Asset Sourcing System (MASS) - → System queries Regional Supply Squadron (RSS) Headquarters at Langley AFB for Regional End-item Availability	10 min	27 min	NVA
3f. RSS Response on shipping serviceable asset from other location	< 24 hours (Typically within 8 hours)	507 min (8.45 hrs)	NVA
3g. End-Item Shipped from Regional Location by LTL Express service to Central Base Warehouse then Distributed to Proper on-base location	24 hours (1440 min)	1947 min (32.45 hrs)	NVA
4. Once end-item delivered to flight line supply section, it is logged into Tail Number Bin (TNB) Facilitate Other Maintenance (FOM) for original aircraft – → If MICAP item, supply notifies avionics specialist upon arrival → FOM is designated by 350 Tag; End-item is not available for other aircraft	5 min	22 min 1952 min (MICAP)	VA
5. Avionics Specialist Signs Part out of TNB for original aircraft when ready for maintenance -	5 min	27 min 1957 min (MICAP)	VA

Table 3.3: Aircraft Cannibalization VSM Time Line

Action	Time to Accomplish	Cumulative Time	VA, NVA or NVAE
1. Once a Cannibalization request is approved the VSM becomes the Cannibalization Process until the end-item is removed from the CANN aircraft and moved to the TNB.			
1a. CANN Dock Removes End-item from CANN Aircraft -	20 min (MLPRF)	47 min (Tbl 3.2, 3c)	NVA
1b. At same time avionics specialist remove failed end-item from original aircraft - → No time added assuming failed and CANNed items removed at same time and rate. → Duplication of effort involved in CANN.	20 min (MLPRF)	47 min	VA
1c. Move CANNed end-item to TNB for Proper documentation by flight line supply technician – → Done in order to keep paperwork straight and ensure no outstanding order against the original aircraft exists, but only against the CANN Aircraft	5 min	52 min	NVAE
1d. Take replacement end-item from TNB to Aircraft and Turn-in Failed end-item for Due-In From Maintenance (DIFM) requirement -	5 min	57 min	VA
1e. Place "Serviceable" CANNED end-item onto original aircraft -	20 min (MLPRF)	77 min	VA
1f. Complete Operations Check and Follow VSM For AMU	60 min	137 min	NVAE
1g. Complete DIFM paperwork and Turn in Failed End-item to Avionics Test Station -	5 min	142 min	VA

3-2-2 AMU Value Stream Map Observations:

To provide an understanding of the avionics sustainment system, it is necessary to assume that end-items and piece parts are always available upon request. Also, end-item removal times are based on the MLPRF's removal from the aircraft, which while it only provides the time length of one end-item, allows the conceptual tracking of the flow of all avionics end-items through the VSM. A complete overview of the flight line VSM is provided in figure 3.9. Any actions above and beyond those of actually pulling the end-item from local inventories or pushing the failed end-item back into the reparable inventory, such as cannibalization and RSS inquiries, are not considered in the calculation of the VSM time. Therefore, the VSM time is

based on the standard actions, if an ideal system existed, and identifies waste in that "standard" sustainment system. However, the over and above actions cannot be forgotten as they are routinely taken when serviceable end-items are not in the sustainment system, and always occur in the case of MICAP, or other high-priority backorders. For the last two years, the MLPRF has been identified on a top 15 MICAP list by the F-16 SCM. Therefore, it is necessary to address the great increase in time when serviceable end-items are not available in standing inventories.

By labeling the various tasks as VA, NVA or NVAE the "value creation" of the avionics sustainment system can be estimated. Any task that is labeled as NVA is considered waste, by not adding value to the sustainment system and should be eliminated to allow the system to flow. Likewise, any task labeled NVAE, is necessary, but could most likely be accomplished in a more effective manner. The aircraft maintenance unit VSM had the following time and task break-out; VA, 93 minutes; NVAE, 94 minutes; and NVA 10 minutes.

The flight line sustainment system is already fairly lean. The only NVA task is the avionics specialist having to walk to the supply support section to check on end-item availability. The bulk of time dedicated to NVAE tasks are to ensure that the replacement end-item does in fact correct the discrepancy on the aircraft through operations checks, and that the avionics specialist documents the repair of the aircraft in CAMS for historical record. Both of these tasks are essential to aircraft repair, but do not add value to the repair and replacement of the end-items.

If cannibalization actions were taken, the NVA task time would increase by an average of 45 minutes for the completion of required additional paperwork, and secondary removal of the end-item being cannibalized from another aircraft. When cannibalization actions fail or cannot be initiated, then it is necessary for the base to contact the RSS to acquire a serviceable end-item from elsewhere in the CSI. On average, the additional time to acquire an end-item from the RSS is on the order of about 32 hours, if the end-item is available in the CSI at another location than the requesting base. The bulk of the time is the time it takes the RSS to respond to the MICAP request, and the time it takes to ship the end-item from its present location to the ordering base. There is an additional 20 minutes of paperwork and entering of information into the MASS information system that is accomplished by the flight line supply support personnel. The length of time it takes to acquire a serviceable end-item from off-base resources drives the aircraft maintenance unit to look for cannibalization options before ordering from the RSS. The response time from the RSS is reasonable for the urgency of need, but there is considerable

waste incurred by the AMU in waiting for end-items to arrive in flight line supply support to complete repairs. This urgency of need is addressed in later chapters, as to whether reduced piece part and end-item stock levels are cushioned by an overage of aircraft.

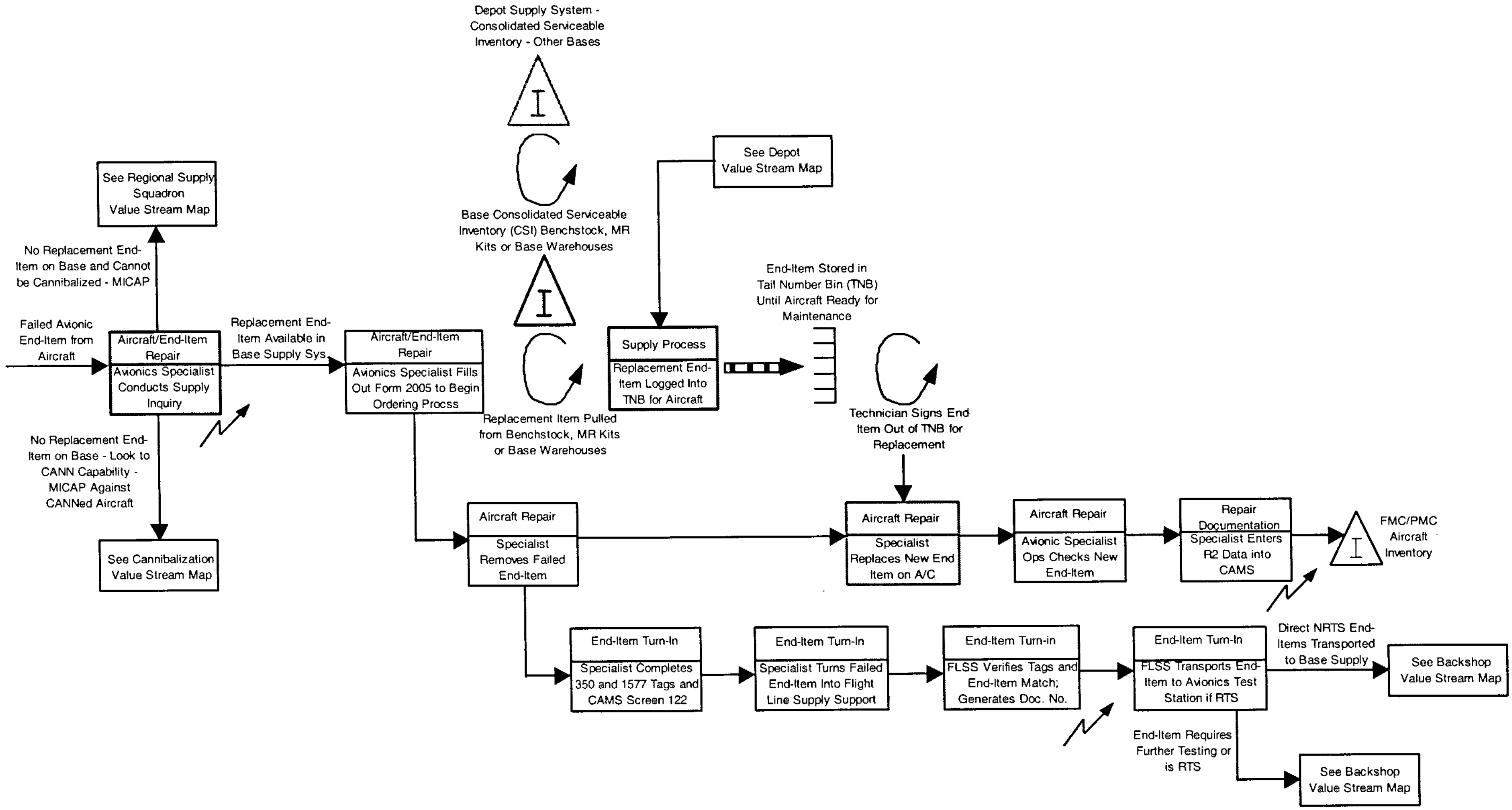


Figure 3.9: Overall View of Aircraft Maintenance Unit Value Stream Map

3-3 Base Supply and Avionics Test Station:

While flight line repair and base backshop repair and testing have been segregated for easier VSM interpretation, in reality, all maintenance activities are a part of a single, larger maintenance group. Therefore, a close working relation is observed between flight line maintenance, namely avionics specialists, and backshop maintenance, for RTS end-items, since the larger maintenance group is focused on keeping aircraft flying. The backshop that relates directly to the avionics sustainment system is the Avionics Testing Station (ATS). ATS personnel are authorized to open LRU end-items and test them on portable test stations, but their repair capability is limited to cross-cannibalization between end-items, for Two-Level Maintenance items, only if they have more than one end-item in the shop at a time. The ATS acts as an initial filter for possible No Fault Found (NFF) or Cannot Duplicate (CND) end-items, which are end-items that may have been failing on the aircraft, but actually have no internal failures and are performing within specifications. This initial testing is helpful to the depot in identifying initial errors and cutting down on the amount of NFF items entering the shop. However, the ATS only has the ability to detect initial failures and not run complete tests to detect all failures. If tests are failed on the test stand, and there are no possible cross-cannibalization options, the failures are documented and the end-item is then shipped off-base to the depot for repair.

If an end-item is a direct NRTS item, then it is automatically moved to base supply for shipment to its respective depot or contract repair facility. End-items that are deemed direct NRTS are not handled by base backshop repair activities. The most typical reason for a direct NRTS item is that these items are under warranty from a contract source of repair. Therefore, any attempt to repair the end-item at base level would void the warranty, so it is immediately shipped to the contract repair facility. Another reason is the technical complexity is beyond that of the capabilities of the base flight line and backshop testing/repair, so the end-item is immediately shipped to depot repair. Most avionics end-items are tested at base level before shipment to depot. Both Value Stream Maps, RTS and direct NRTS, are outlined in the following sections.

3-3-1 Base Supply and ATS Value Stream Map Processes:

The standard VSM for avionics end-items pushes the items through the ATS, otherwise known as a backshop. The ATS, a centralized testing facility for all base operational aircraft squadrons, receives the end-item to be tested from the flight line supply support personnel. ATS personnel verify there are no paperwork errors by assuring that the forms and end-items, they receive, match. The backshop personnel then log the end-item into two information systems, one legacy system and one local system, for tracking purposes. Also, they log the items manually into their LRU logbook in the event that the information systems become unavailable. The testing and repair technician then prepares the test stand and prepares the end-item for failure testing. This typically only takes a few minutes on their newer, more mobile IAIS test stations. The longest set-up takes about thirty minutes because it requires a pressure check of the Dual-Mode Transmitter (DMT). This part of the VSM is presented in figure 3.10 below.

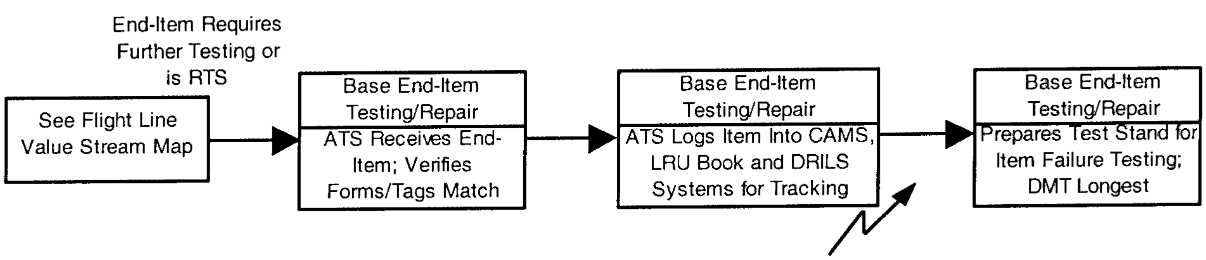


Figure 3.10: End-Item Induction into Avionics Test Station

Once the end-item is properly attached to the test stand, the failure test is run on the item. This testing can take anywhere from thirty minutes to seven hours depending on the end-item and the amount of manual intervention required in the testing phase. The MLPRF typically takes about 1 to 1½ hours. The Digital Flight Control Computer typically takes the longest to test.

Testing continues until a failure is detected by the test stand. The technician then tries to reseat the failing component, a Shop Replaceable Unit (SRU) circuit card, and then re-runs the same test. If the failure continues, the technician retests the SRU again to make sure the failure is not being caused by a software problem in the test stand. After the second failure, the technician can cross-cannibalize SRUs if another end-item is available. If there are no other end-items available, the technician is required to consider the failing end-item NRTS. However, if the failure is corrected by the reseat or retest actions, the test continues until the next discrepancy

is detected. Additional discrepancies require the same manual intervention action. This process is clarified by figure 3.11, and shows the iterative nature of the process.

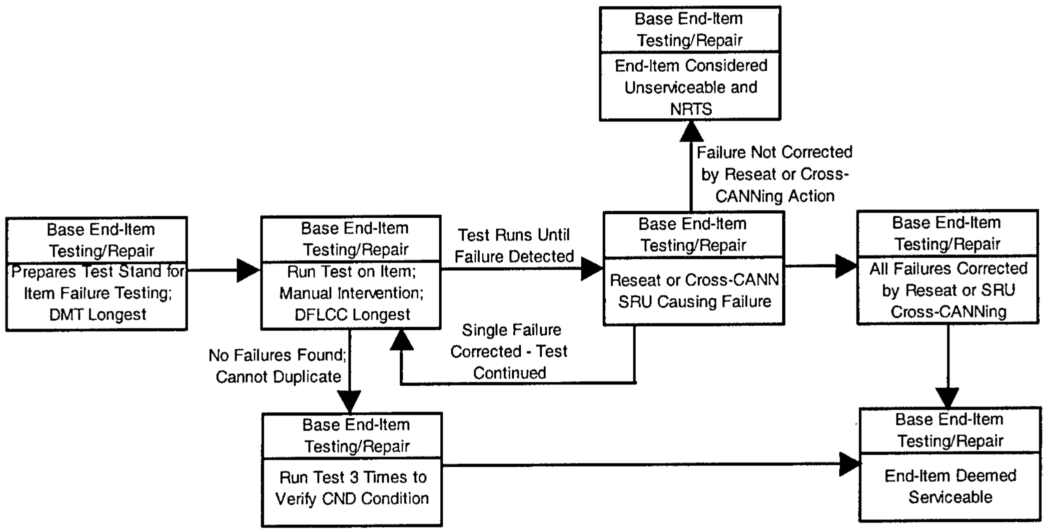


Figure 3.11: End-Item ATS Testing and Repair Actions

This iterative process continues until the end-item passes all tests or fails a test after corrective actions have been taken. End-items that pass all tests are considered serviceable end-items. In some instances, end-items have no discrepancies during testing, and are considered CND or NFF. These items are retested three times to ensure no failures are detected. As long as failures do not occur, the end-items take the minimum amount of testing time. If, indeed, these items have no failures they are also considered serviceable. Figure 3.12 shows the movement of the various categories of end-items; direct NRTS, NRTS and serviceable, to base supply for distribution to their respective stocking locations.

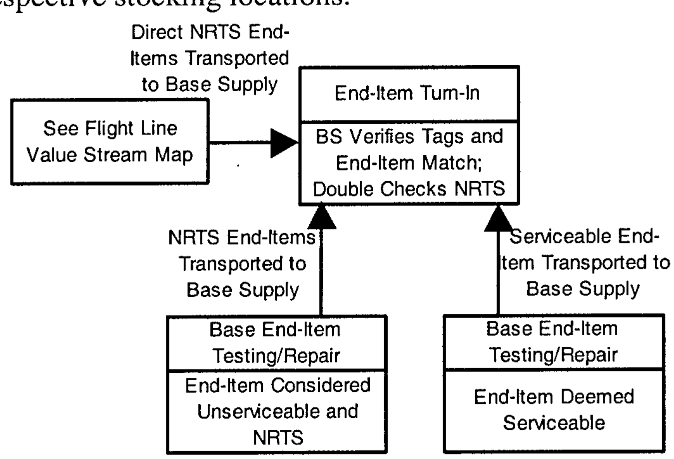


Figure 3.12: Direct NRT, NRTS, and Serviceable End-Item Turn-in to Base Supply

Serviceable end-items are transported to base supply for return to the serviceable inventory, or if a local requisition exists for this end-item, it is immediately used to fill that requisition. If no local requisition exists, then the end-item becomes visible in the world-wide SBSS for possible fulfillment of other requisitions, and follows the VSM for direct NRTS end-items through base supply, figure 3.13.

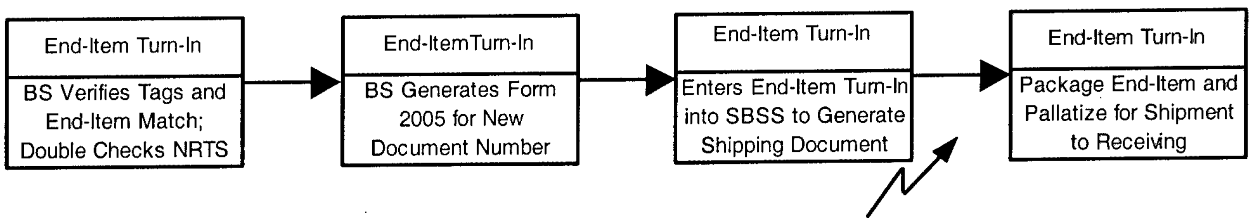


Figure 3.13: Base Supply End-Item Induction and Shipping Process

The VSM for direct NRTS end-items, figure 3.13, requires flight line supply support to immediately move an end-item to base supply upon receipt from the avionics specialist. Base Supply, much like the ATS, verifies that all forms and tags match the end-item being turned in by flight line supply support. The base supply technician then generates a new order form 2005, in order to acquire a new document number. This document number is then input into SBSS to generate the necessary shipping documents. For unserviceable end-items, the shipping document generated indicates which repair facility, depot or contract, the end-item is to be shipped to for refurbishment. If the end-item was turned in as serviceable from the ATS, then the shipping document indicates where the serviceable end-item should be placed in local inventory or it is to be used to fulfill a local requisition. The unserviceable component VSM is important in ensuring adequate amounts of reparable items are in the sustainment system to support depot/contractor refurbishment operations.

The end-items, serviceable and unserviceable, are packaged and palletized for shipment to base shipping and receiving, unless of course they are filling a local requisition. In this case, the end-item is transported directly to the requesting flight line supply support function. The packaged items are then palletized separately depending on serviceable and unserviceable, and moved to base shipping and receiving. When the end-items arrive at base shipping and receiving, a Less-Than Truck Load (LTL) shipping company is contracted to transport the unserviceable end-item to its correct consolidated reparable inventory (CRI) location, which is

typically the same location as the depot or contract repair facility. The serviceable items, if not kept at the same base, are also transported by LTL carrier to pre-determined inventory locations. When unserviceable end-items are moved to the CRI, the depot repair process begins when an requirement is generated for repairing this end-item. The VSM for moving items from base supply to CRI or CSI is exhibited in Figure 3.14.

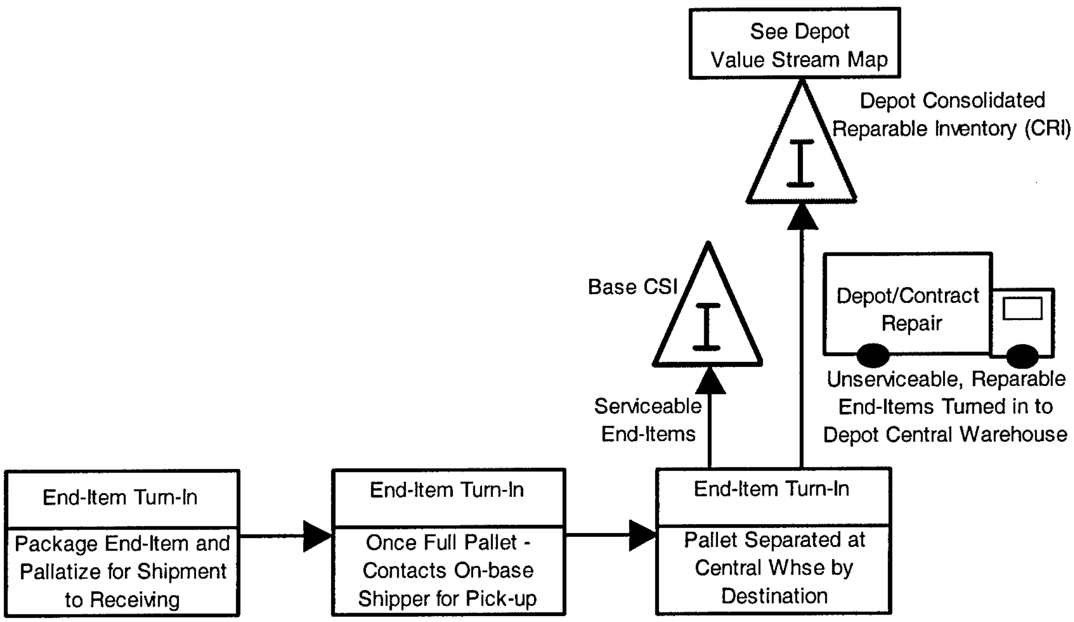


Figure 3.14: Serviceable End-Items to Base CSI and NRTS End-Items to Depot CRI

The following tables outline the time each task takes in the ATS and base supply section of the VSM. It also labels each task as VA, NVA, and NVAE as explained in section 3.1 of this chapter.

Table 3.4: Avionics Test Station VSM Time Line

Action	**Time to Accomplish**	**Cumulative Time**	**VA, NVA or NVAE**
1. Receive End-item from Flight Line Supply Support → Verify Forms (Tags) 1348 & 350 with End-item (Document Numbers) → Verify Part and Serial Number with printed Screen 122 from CAMS	1 min	1 min	NVA
2. Log End-item into CAMS, LRU Book and in the case of the 388^{th}, Depot Repair Information Local Server (DRILS) for tracking purposes	10 min	11 min	NVAE

3. Set-up End-item on Test Stand → Use IAIS Mobile Test Station (3 on-hand, 1 per squadron) → Newer version of stationary Depot Test Stands – some software conflicts	5 min	16 min	VA
3a. Before Testing begins – run initial system checks - → Dual Mode Transmitter (DMT) requires Pressure Check	10-30 min	36 min	NVAE
3b. Run Test on End-Item → Test time varies because some items require no manual intervention, while others need a lot of manual intervention	20 min to 7 hrs 30-45 min (MLPRF)	76 min (MLPRF)	VA
3c. Failure Detected – only course of action is to re-seat SRUs (2LM only on most avionics)	5 min/ occurrence	91 min (3 re-seats)	VA
3d. Hard failure (re-seat did not work) then item immediately considered NRTS; End-test and Remove from Test Stand	10 min	101 min	VA
4. NRTS Item is sent to base supply (Walked by ATS personnel to Base Supply) → End-item status changed from ATS to NRTS	5 min	106 min	NVAE
5. If Failure CND, then run test three times -	40 min avg (MLPRF)	120 min	NVAE
6. CND Item turned into base supply as serviceable then base supply takes over item → Same is done for items that are repaired by re-seating SRUs	5 min	125 min	VA

Between steps 2 and 3 there is possibly a wait period for an open test stand. This type of wait rarely exceeds one shift (8 hours). Most of the waiting that occurs is caused by Time Compliance Technical Order tests on MR kits. These checks require operational checks on all end-items in the MR kits, which can cause a work backlog in the shop. However, because of the work prioritization outlined in AFI 21-101, items brought to the ATS from the flight line are tested when the next test stand becomes available.

Table 3.5: Base Supply VSM Time Line

Action	**Time to Accomplish**	**Cumulative Time**	**VA, NVA or NVAE**
1. Receive End-item from ATS or from Flight Line Supply Support	1 min	1 min	NVA

→ Verify Forms (Tags) 1348 & 350 with End-item (Document Numbers) → Verify Part and Serial Number with printed Screen 122 from CAMS			
2. Double check to ensure item is NRTS (unserviceable end-items) → Ensure direct NRTS if coming from FLSS → Ensure test failure documentation with item coming from ATS	2 min	3 min	NVAE
3. Complete Order request form 2005 to create DIFM requirement and order replacement item if applicable → Generates Doc. Number for Tracking	5 min	8 min	NVAE
4. Enter Document Number into SBSS for Shipping Document	5 min	13 min	NVAE
5. Attach Shipping Document to End-Item and Package In Approved Container	15 min	28 min	NVAE
6. Build-up On-Base and Off-Base Pallett	Avg 1-2/day (4 hrs/pallet)	268 min	NVA
7. Full Pallett → Contact Off-base LTL Shipper for Pick-up → Move Items to Central Base Warehouse using On-Base Shipper (Contractor)	10 min to 3 hrs for Pick-up	328 min	NVAE
If Item is Turned in Serviceable from ATS:			
8. Enter Item into SBSS – → If no requirements (orders), generates notice to stock item → If requirement exists, system releases item to fill requirement – have 24 hours to fill on-base requirements first then worldwide visibility after 24 hours	5 min	13 min (Steps 1-3+8)	NVAE
9. If on-base requirement, moved directly to flight line supply support section	5 min	18 min	VA
10. If off-base requirement continue with Steps 4 to7 of shipping process			

3-3-2 Base Supply and ATS Value Stream Map Observations:

While there are two paths end-items can take out of the flight line supply support section, only one typically pertains to avionics end-items. The most likely path for the avionics is to flow from flight line supply support to the ATS where they are tested to ensure that the end-item is actually failing. The other path is referred to as "Direct NRTS", which is typically the path items follow if they are under warranty from a contractor, and any intervention, other than that of the

contractor, would void that warranty. The standard VSM task time for the base backshop repair and supply functions breaks-out into the three classifications as; VA, 80 minutes; NVAE, 207 minutes; and NVA, 242 minutes. A complete overview of the ATS and base supply VSM is provided in figure 3.15 below.

The NVA task time of the backshop VSM is considerably greater than that of the flight line. This is actually caused by waiting in base supply for end-item shipment back to serviceable inventory, if there are no immediate requirements, or for shipment to the depot reparable inventory, if unserviceable. The various unserviceable end-items are mixed together on a single pallet according to destination. All end-items going to the same depot or contract repair facility are batched together to take advantage of shipping economies of scale. At the 388th FW, these pallets are sent from the base to depot at least once a day, but usually twice a day. Therefore, the four hour (240 minute) wait for pallet completion is the greatest waste. Additional waste results from the need to verify end-items with tags and paperwork at every station, which takes at least a minute per end-item. While this is very little wasted time, there may be a better way of ensuring documentation matches the end-item without countless verification.

The NVAE task time of 207 minutes consists of mainly two tasks, one of which does not always occur, but must be considered because it ties-up valuable resources. In cases where no failures of the end-item are detected on the test stand, the tests are run three times to confirm that no fault is found. For an end-item, such as the MLPRF, each test takes at least 40 minutes without any intervention, which would be the case if no failures occurred. Therefore, in addition to the initial test, the test needs to be run two more times, and if no failures occur the item is deemed serviceable and is turned into base supply. The other key contributor to the NVAE time, is waiting for an LTL Carrier to pick-up the pallet from base supply for shipment to the depot. This wait can be as little as 10 minutes to as much as three hours. On average, the wait is about 60 minutes. The rest of the NVAE time is added by the entering of information into electronic systems, and checking and completing required paperwork.

The MLPRF is the end-item being used as a guideline for the VSM task time. This time fluctuates depending on the avionics end-item and whether or not the item is a MICAP. MICAP end-items receive the highest priority and, therefore are shipped considerably faster than if an end-item, which has numerous serviceable counterparts, is being turned in to the reparable inventory. The value added aspect of the ATS and base supply VSM constitutes about 80

minutes or 15 percent of the entire time an end-item is in the backshop section. The most value is added when the end-item is initially tested on the test stand and the technician is receiving information about what parts of the end-item have failed.

There is one drawback to this process. The base operates a different test stand than the depot, so a lot of the information garnered from testing at the base is lost in the transfer of the end-item to depot repair. This requires an almost duplicate effort at the depot to retest the end-item. Developing an information system by which test failure information could be passed to the depot ahead of the end-item, and possibly integrating a Just-In-Time supplier delivery to typical parts, associated with failure, could greatly enhance the flow of end-items to and from the depot. This enhancement is discussed further in the recommendations chapter of this thesis.

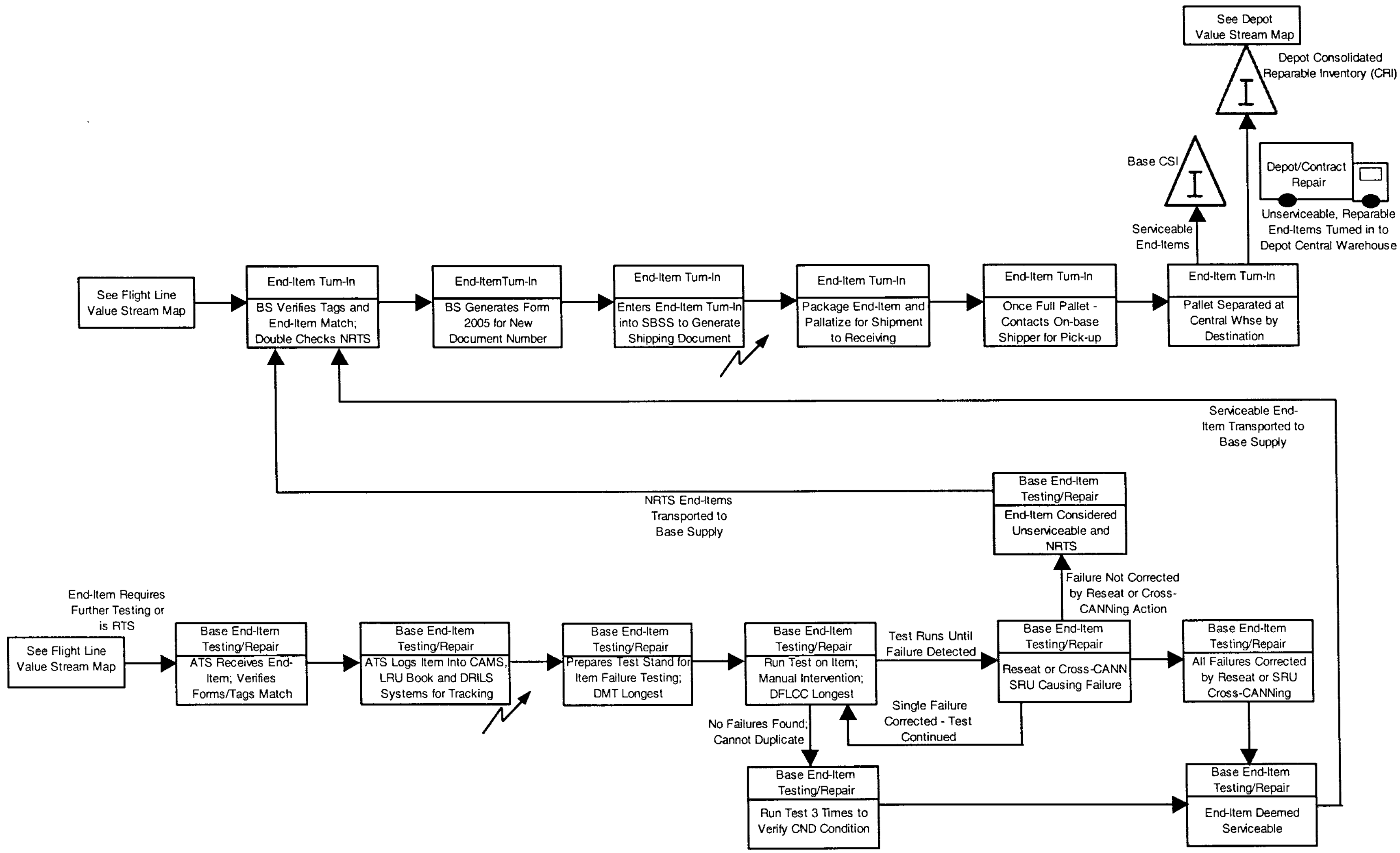


Figure 3.15: Base Supply and Backshop Repair and Testing Value Stream Map

3-4 Depot Repair, Testing and Supply:

The bulk of the avionics sustainment system occurs at depot level. The depot is responsible for determining which items will be repaired and in what manner. This chapter, while focusing only on end-item flow through the system, neglects the important administrative aspect of operations. This includes, but is not limited too, the material management team leads (MMTL) and supply chain manager (SCM), as well as the lead fixer, which dictates shop production schedules. Therefore, these important positions will be discussed in the next chapter under the organizational context.

End-items flow into the depots from numerous base-level organizations, so the depot prioritizes the repair of these items by their importance, e.g. backorders, and by quarterly negotiated repair quantity goals, e.g. requirements determined by MMTL. Depot also repairs some of the SRUs that have failed and been removed from LRUs. The main focus is on the flow of end-items and not piece parts; however, the flow of piece parts has a extraordinary impact on the flow of end-items. Piece parts and/or SRUs can be repaired, if determined to be reparable items, at the depot or contracted to a commercial company. A majority of the non-reparable or consumable parts, which are much less expensive in comparison to reparable items, come directly from contractors or the Defense Logistics Agency (DLA) and are maintained at preset stock levels as determined by quarterly negotiations.

The value stream map of end-items flowing through the depot can be analyzed in three sections. The first step in the depot VSL is the end-item's arrival at depot, and its induction into the repair shops. The second section is actual end-item repair. The final section is the movement of the refurbished, serviceable end-item back to the consolidated serviceable inventory (CSI), from which bases draw their requirements from, or directly to bases to fulfill MICAP requirements. This last section closes the loop from the base to the depot, and demonstrates the highly interactive nature of this system.

3-4-1 Depot Repair, Testing and Supply Value Stream Map Processes:

The depot VSM begins with the movement of failed end-items to the Consolidated Reparable Inventory (CRI) from bases. The goal of depot management is to determine the right amount of end-items to have in the sustainment system so there are always a few LRUs requiring repair and

a few in the serviceable inventory, strategically pre-positioned, for bases to draw from to keep aircraft flying safely.

For depot repair to begin, the workload manager is required to induct the end-item into the repair shop through the use of several different software systems. The workload manager is responsible for inducting LRUs into the shop, as well as for selling serviceable LRUs back to the CSI. The workload manager knows which items to induct on a daily basis based on the negotiated repair quantity that is determined each quarter by the MMTL and fixer. The MMTL usually has requirements that are higher than the depot negotiated repair quantity as determined by the fixer based on capacity, funding and organizational constraints. In the case of the MLPRF, the Radio Frequency (RF) shop fixer negotiates these quantities with the MMTL. While the workload manager is only required to induct the negotiated quantity on a quarterly basis, they try to achieve the higher, required quantity.

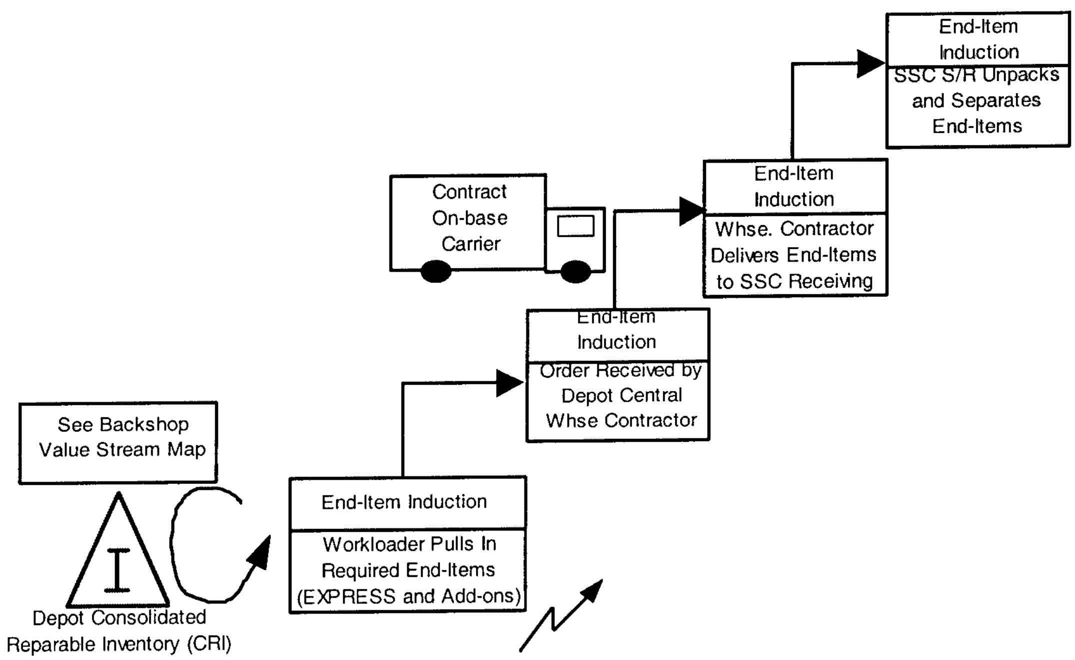


Figure 3.16: End-Item Induction into Shop Service Center

The workload manager orders in the unserviceable, "F" condition as labeled by software systems, end-items to be brought to the Shop Service Center (SSC) shipping and receiving (S/R) area. The SSC induction process is demonstrated in figure 3.16 and begins with the ordering in of these end-items. The time from order placement to actual arrival in SSC S/R varies from a

few hours to several days depending on the priority of the end-item. For MICAPs, the most it ever takes for the items to be delivered is three hours. However, the depot warehousing and shipping contractor only operates during regular business hours, 0700 to 1630, so this delivery time depends on the time of order placement. The workload manager tries to order all end-items, for a days worth of work, early in the morning for possible same day delivery. However, it can take up to two days until an end-item is delivered. This delivery time is highly variable and dependent on the depot shipping contractor's availability.

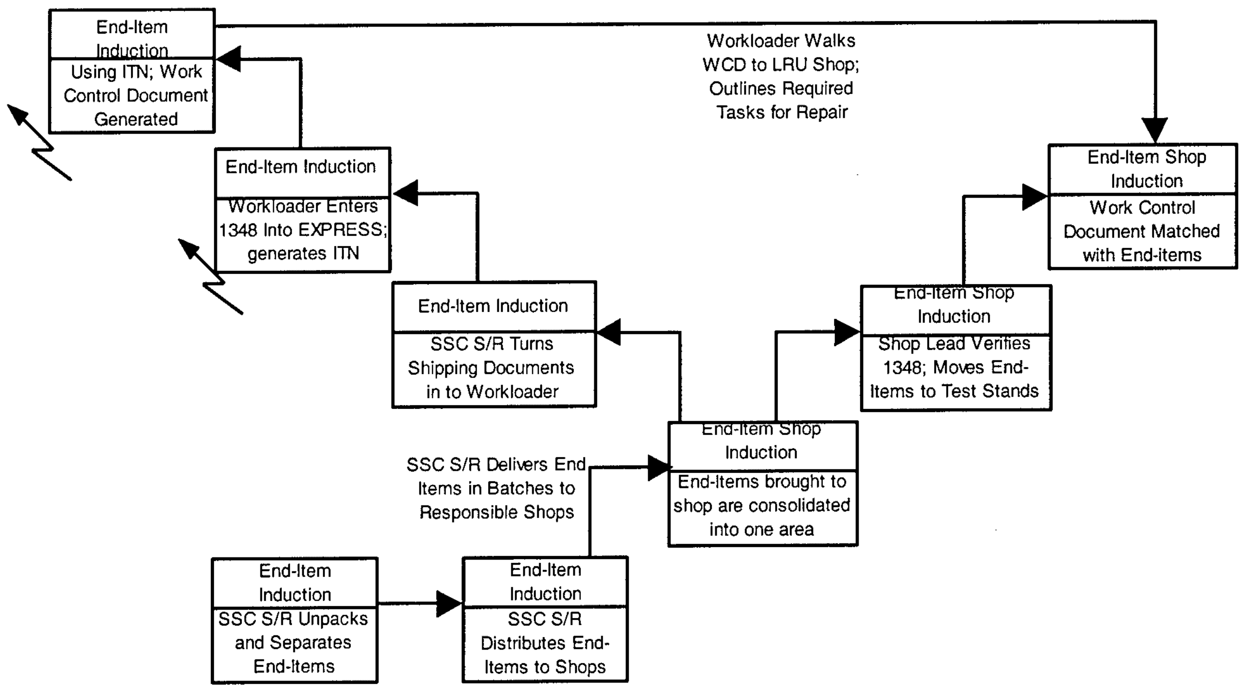


Figure 3.17: End-Item Moved from SSC to Depot Testing and Repair

Once the end-item is delivered, SSC S/R personnel unpack the end-item and manually move it to its proper repair shop, shown in figure 3.17, located in the same building. They also deliver the shipping document, Form 1348, to the workload manager, so she or he is aware that the item has been delivered to the shop. The workload manager then enters the 1348s into EXPRESS (DO87) software system to complete induction and generate an inventory tracking number (ITN) that is tied to the end-item serial number while the LRU is in the repair shops. The 1348s are entered in batches, much as the end-items are unpacked at the SSC S/R area, because of the ease of working the LRUs in batches as they are delivered. Once the ITN is acquired, the workload manager generates a Work Control Document (WCD) number and repair sheet for the

technicians to document all work completed on a particular end-item. This WCD is generated in the Inventory Tracking System (ITS) using the ITN. The WCD also spells out the steps that the technician must follow in testing the end-item for serviceability. The workload manager then hand-carries the WCD to the applicable LRU shop technician working on the end-item or places with items awaiting maintenance (AWM). Items may be AWM due to equipment or personnel downtime or by the requirement to over induct items from the depot warehouse to support 16 hour repair operations, two 8-hour shifts, since the depot warehouse operates only during the regular business day. In most ideal situations the workload manager needs about 30 minutes to induct end-items into the shop for repair.

The repair shop VSM begins with end-item delivery to the shop by the SSC S/R personnel. Before the SSC personnel take the 1348s to the workload manager, the shop supervisor verifies that the forms and serial numbers on the end-items match. The shop supervisor also accepts the WCDs from the workload manager on end-items awaiting maintenance. The shop supervisor then distributes the end-items to the various test stands for testing and repair. The supervisor is familiar with which machines interact best with certain types of end-items. For example, one test stand may have problems running the tests for the MLPRF, while another runs the tests faster and more accurately than any other test stand in the shop. There are five test stands in the RF depot shop that work well with the MLPRF end-item. These items may wait from one to eight hours for repair because there is another end-item in-work (INW) at the time of induction. This wait, however, is rarely ever more than one eight-hour shift, since the end-items are not specifically designated to each machine, they can be moved to another test stand if there are problems with the original station. Once these induction steps are completed, testing and repair can begin on the end-item. Therefore, the induction of end-items from the CRI to the test stand takes a little over four and a half hours, most of which, four hours, is accounted for in awaiting delivery of the end-items from the central depot warehouse, and AWM due to test stand availability.

The tables throughout this section outline the time each task takes in the depot repair, testing and supply VSM. It also labels each task as VA, NVA, and NVAE as explained in section 3.1 of this chapter.

Table 3.6: End-Item Induction VSM Time Line

Action	Time to Accomplish	Cumulative Time	VA, NVA or NVAE
1. Order in "F" Condition (Reparable, Unserviceable) End-Items into SSC S/R → Need to have Carcasses available in CRI to order into shop → EXPRESS Drives in items, but workload manager can intervene and add or subtract from EXPRESS drive in quantity	5 min/item	5 min	VA
2. Time Order Put in to Time Item Reaches SSC S/R could be 1-2 days depending on Priority → MICAPs delivered within 3 hours	180 min (MLPRF)	185 min	NVA
3. SSC S/R Unpacks End-Item, Moves unit to Shop, Gives Shipping Form (1348) to Workload manager with End-Item Serial Number Annotated (Batched Process)	5 min/unpack 5 min/item to shop 5 min/1348 to workload manager	200 min	NVAE
4. Workload manager enters 1348's into EXPRESS to Complete Induction; Generates an ITN for the Serial Number (Batched)	2 min/1348	202 min	NVAE
5. Using ITN, Workload manager Generates a WCD Number (Old Form 959) and Sheet for Technician to Document Work Completed	2 min/WCD	204 min	NVAE
6. Workload manager hand-carries WCD to LRU Shop Technician Working on end-item or places with item AWM (Batched)	10 min	214 min	NVA
7. Item brought into Shop by SSC S/R personnel → Inducted into shop by Shop Supervisor → Verifies Forms and S/N Matches → Accepts WCDs from workload manager	2 min/item	216 min	NVAE
8. Item(s) distributed to Test Stands for Testing/ Repair → Time varies depending on amount of items	5-15 min	221min	VA
9. Item(s) may wait for Testing/Repair if another Item is In-work → Wait no longer than one shift (8 hours)	1-8 hours	281 min	NVA

Once end-items are delivered to the depot repair shop, the shop supervisor may distribute the end-items to the various test stands. However, the supervisor typically stores end-items AWM in a central shop location, visible to all technicians. A large white board informs the technicians how many of each end-item the shop has to produce each week to meet the quarterly negotiated

quantity. The board also displays the required quantity as established by the MMTL. The technicians use this to determine which item they will repair next by matching available carcasses to the quantity needed each week to meet this negotiated quantity. All technicians are well versed in determining what is required, as well as which items test well on their test stand. Additionally, since the shop operates on two different shifts, the technicians maintain a logbook of items repaired on the machine, so that when the next shift starts, the new technician knows what has been done with an end-item that may be in the middle of testing.

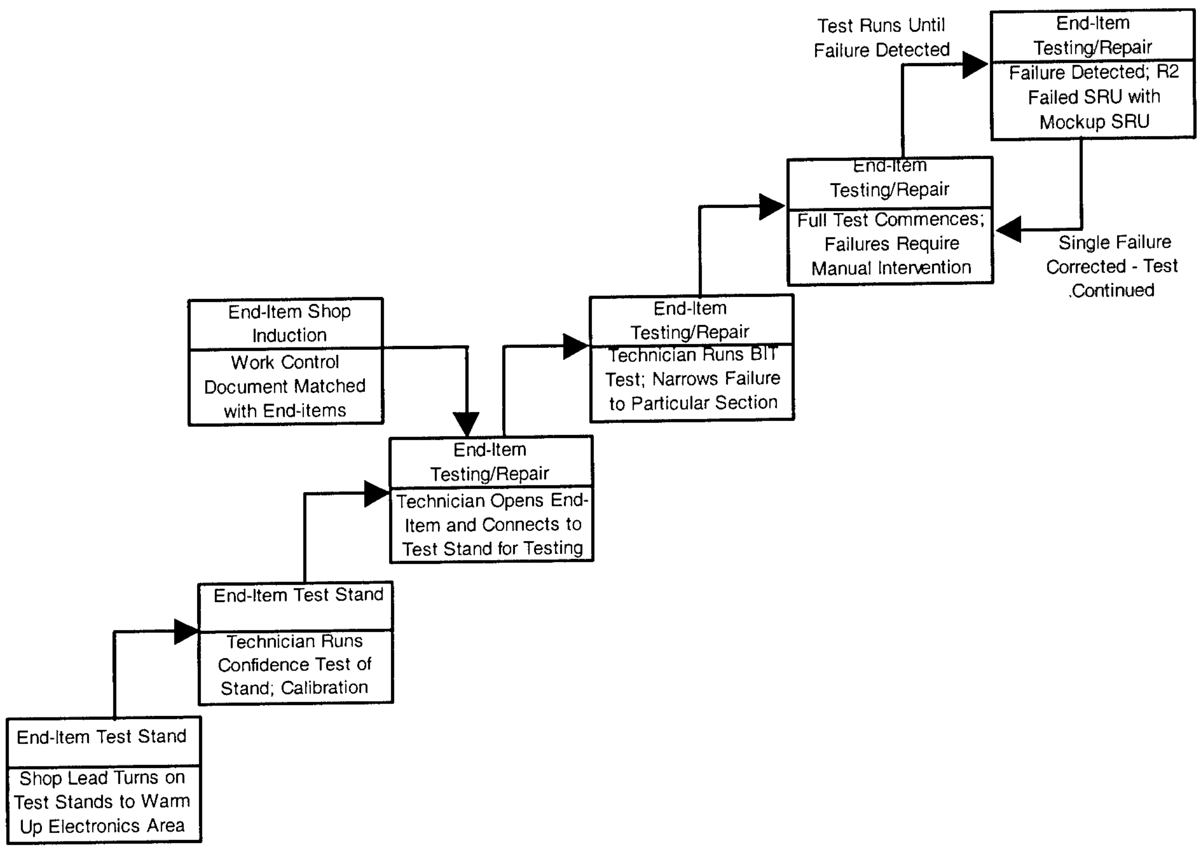


Figure 3.18: End-Item Depot Testing and Repair

After the end-items' induction and distribution to the repair shops, the actual testing and repair process begins. The actions associated with end-item repair and testing are exhibited in figure 3.18. Before testing can begin on any shift, the technician runs a confidence test on the test stand to make sure all the software and hardware components are operating properly to ensure end-item test integrity. In order for the test stands to operate accurately, they need a stable ambient air temperature. This requires the machines to be turned-on at least 30 minutes

before testing begins to warm up the shop area to a stable temperature. While the shop is well air conditioned, the heat generated by all the machines operating can raise the room temperature at least 10 degrees. The confidence test is very quick, but can take anywhere from five to thirty minutes depending on boot problems or equipment not turning on at the first attempt. The end-item, if not already from a previous shift, is connected to the test stand to begin testing. The connectors are changed during testing to test various aspects of the end-items capability and possible failures. This requires the technician to be familiar with the connections and at what times to change the connections. This can have a considerable impact on the amount of time testing takes. The VSM is based on a technician of reasonable experience, but not an expert on the test stand.

Testing and repair begins with a quick and simple BIT test that tests the various circuitry loops in the end-items to help narrow down where specific failures may occur on the end-item. For example, the MLPRF has three specific circuitry loops that the BIT test analyzes. After the BIT test, the technician begins the longer, more stringent test that checks every SRU and circuit for failures based on operating parameters. One end-item may have many tests for each section or part. The MLPRF has 28 independent tests, and each test requires different connections, which introduces manual intervention to change hook-ups between the different tests. If a test is failed, it is rerun to make sure the test stand did not encounter an internal software problem. If upon retest, the test is failed again, then most likely the SRU being tested has failed in some manner. The technician then removes the suspected failing SRU, and replaces with a "mock-up" SRU, which is a known serviceable SRU that the shop maintains for testing. With the mock-up SRU installed, the test is re-run to see if the failure is corrected. If it is not corrected then another SRU, which may interface with the mock-up SRU, may be causing the test failure. This task is repeated for each failed test and SRU card that indicates a failure on the test stand. Through elimination and trial and error, the exact failure is pinpointed. If the failure is in one of the SRUs, the SRU is turned-in as unserviceable and a new, serviceable SRU is ordered from the SSC.

Replacement SRUs are ordered by the technician with the SSC Production Materiel Technicians (PMTs). There is at least one PMT assigned to each shop. The repair technician starts the ordering process, detailed in figure 3.19, by completing a Form 2005 to generate an order request and provide for a DIFM item. Most SRUs are reparable and not consumable items,

and therefore require a one-for-one swap of unserviceable SRUs for serviceable SRUs. The repair technician hand carries the Form 2005 to the centrally located SSC, since the SSC also supports other LRU repair shops, and presents the order to the PMT. The PMT then determines SRU stock availability in

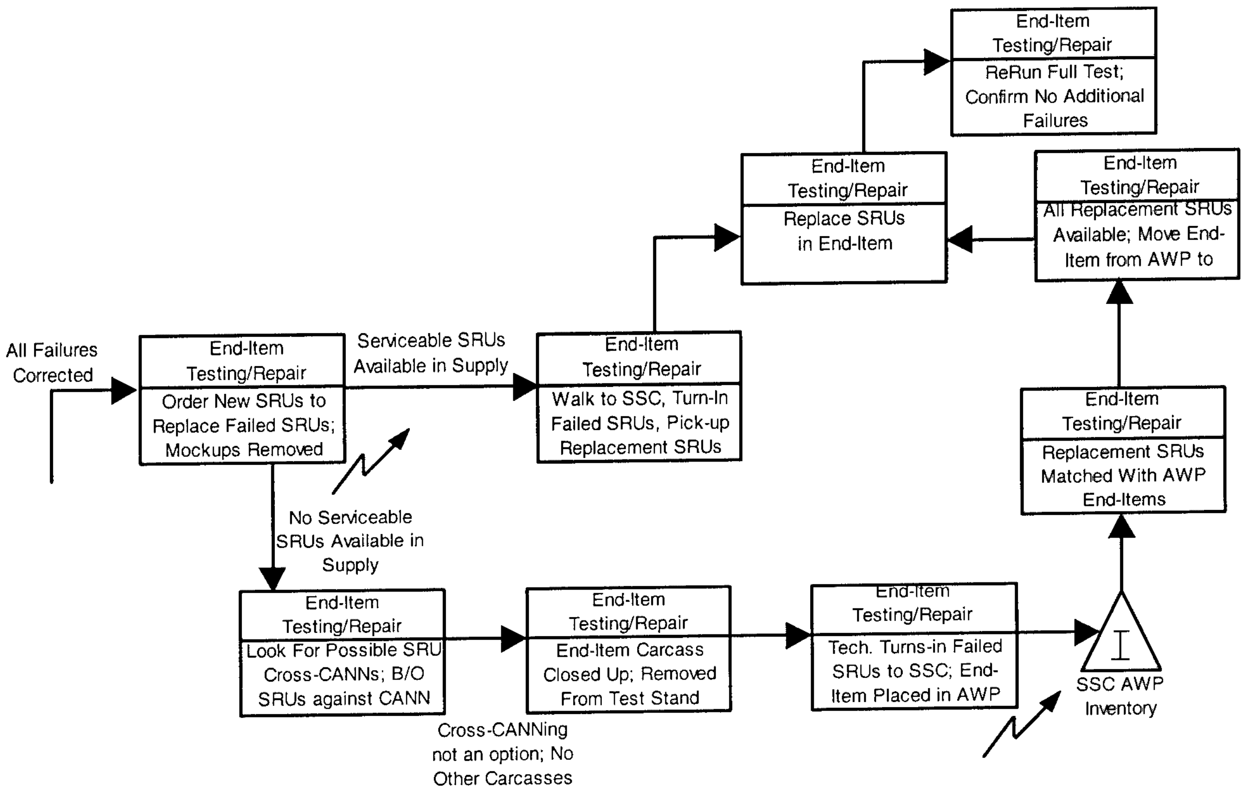


Figure 3.19: SRU Replacement in End-Item; AWP End-Item Handling

DO35K, and if the item is available, he or she submits an order request. The order request subtracts the issued item from the standing inventory, as well as provides a bin location number in the SSC inventory, so the PMT can acquire the item for the repair technician. However, if the item is not available, the order request is attached to the specific LRU WCD and serial number for future backorder match-up. At this point, the repair technician has two options. First, they attempt to cross-cannibalize the SRU with another end-item already inducted into the shop or they can disconnect the end-item and submit it for the awaiting parts (AWP) inventory until the backordered part arrives. Most technicians will attempt to cross-cannibalize the SRU from another end-item, but more times than not, that same SRU is the failed component on the cannibalized end-item.

To continue with the VSM, assume for the time being, that all required SRUs and other parts were available in the SSC. Once the PMT acquires all the requested parts from the SSC standing inventory, the technician returns to their test stand with the serviceable SRUs. The technician then removes the mock-ups, and replaces them with the replacement SRUs from the SSC. To ensure the new SRUs are indeed serviceable, the technician reruns the failed tests.

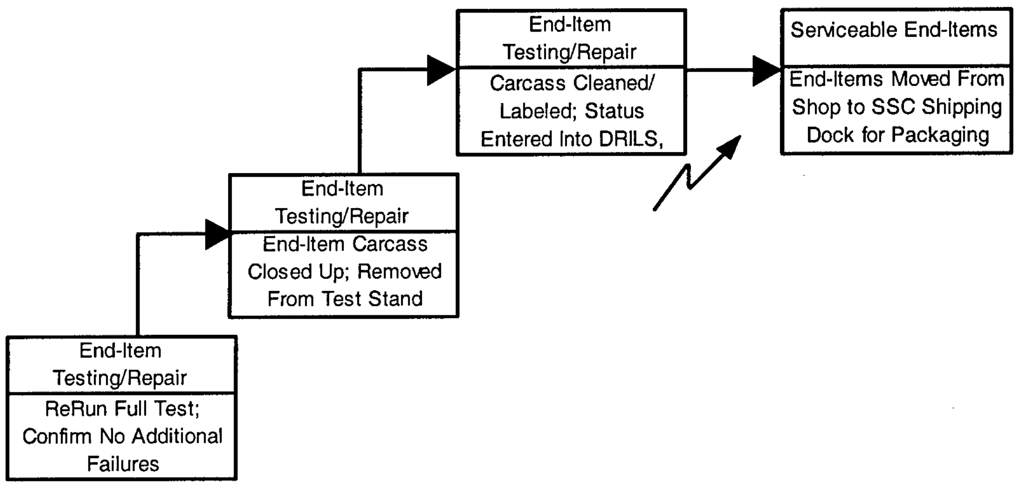


Figure 3.20: Completed End-Item Testing and Repair; Carcass Clean-up

If the LRU passes all tests, it is deemed serviceable, removed from the test stand, and its cover, that was removed during connection to the test stand, is put back into place (Figure 3.20). Completion of the repair process, requires the technician to clean the LRU carcass, including painting exposed metal, fastening and checking all fasteners, capping plug ends, and placing Quality Deficiency Report (QDR) stickers on the carcass to prevent tampering with the LRU by base level maintenance. The technician is also responsible for generating tags, Tag 1577 for NRTS items and Tag 350, to turn-in the original failed SRUs with the corresponding Form 2005 used to issue the serviceable SRUs from the SSC, and inputs the WCD repair documentation into two end-item tracking systems. One tracking system, used locally, is the Depot Repair Information Local Server (DRILS) similar to what the ATS is using, and the other system is the Air Force-wide Depot Maintenance Activation Planning System (DMAPS). The technician then manually moves the serviceable end-item to the SSC S/R area, drops the completed WCD in the workload manager's inbox, and turns-in DIFM unserviceable SRUs to the PMT along with the required paperwork.

Table 3.7: End-Item Repair VSM Time Line

Action	**Time to Accomplish**	**Cumulative Time**	**VA, NVA or NVAE**
1. Shop Supervisor Turns on Machines to Warm Them and Ambient Air Temperature Up to Stable Level → Test Stand requires Stable Temperature for Accuracy (+/- 5 degrees)	30-45 min	N/A to VSM	NVAE
2. Technician Runs Confidence Test on Test Stand → 5 Dedicated MLPRF Test Stands; 7 Dedicated Personnel (4 days, 3 swings) → Test Stands don't always Start on First Attempt; circa 1985 equipment	5-30 min	15 min	NVAE
3. Technician Runs a BIT Test on the LRU → Tests circuitry loops between SRUs for possible failures and helps narrow down failures to specific section of LRU → MLPRF has 3 sections	5 min	20 min	VA
4. Technician commences more stringent tests on each SRU card → Test runs through each section independently, then requires manual intervention to change hook-ups between LRU and Test Stand for different tests → As failures occur, rerun the failed test to make sure not a software glitch. → If fails again, then most likely SRU is bad → 28 Different Tests run on MLPRF	100 min (No failures on MLPRF) 120 min (observed on LRU with two failing SRUs)	140 min	VA
5. When test and retest failed, Technician replaces suspect SRU with "good" Mock-up SRU to determine that SRU has failed → Mock-ups are serviceable SRUs that are dedicated to the shop → Continue test with Mock-up replacement to ensure that failure is in this location → Allows technician to zero in on bad SRUs for replacement by process of elimination	5 min to locate Mock-up SRU 5 min to R2 SRU 2 min to begin retest	164 min	VA
6. Once all failed SRUs confirmed, technician puts in order requests with SSC PMT for replacement parts → Starts by putting together paperwork, Form 2005	5-10 min	174 min	NVAE
7. Technician hand carries Form 2005 to SSC PMT – PMT (if parts in stock) pulls item and gives to Technician	5 min/SRU	184 min	NVA

→ Short walk to centrally located SSC			
8. LRU Shop Technician Comes in with a Form 2005 to order a part from the SSC → PMT Checks SSC availability using DO35K RIAD Screen	5 min	189 min	NVAE
9. If item available, submit order request → Subtracts issue from standing inventory → Provides location in SSC Inventory	10 min	199 min	VA
10. Pull Item from SSC Inventory	5-10 min	209 min	VA
11. Technician returns to Test Stand and Removes Mock-ups and replaces with new, serviceable SRUs	5 min/SRU	219 min	VA
12. Technician Reruns Failed Tests to Ensure new SRUs are indeed serviceable – time varies/test	5-20 min	234 min	VA
13. If LRU then passes all tests, it is deemed serviceable → Puts cover back on LRU	5 min	239 min	VA
14. Cleans LRU carcass → Paints bare spots → Checks all screws are fastened → Places Caps on Plug Ends → Places QDR Stickers to prevent tampering with serviceable LRU	10 min	249 min	NVAE
15. Generates tags to turn-in original failed SRUs and inputs WCD documentation into DRILS and DMAPS → 1577 (NRTS Tag), 350 (Reparable Item Processing Tag), and corresponding Form 2005 that SSC PMT used to Issue Serviceable Replacement SRU	15 min	264 min	NVAE
16. Moves Serviceable LRU to SSC S/R, Drops Completed WCD in Workload manager's Inbox, and Gives Unserviceable SRUs to PMT with Paperwork for DIFM Requirement	10 min	274 min	NVA

Earlier the assumption was made that all SRUs and parts were available for end-item repair at time of request. This is not always the case, and thus requires either of two courses of action in the depot repair shop. First is the cross-cannibalization of SRUs and parts from one end-item to another, and second is the placement of end-items into an AWP status. The MLPRF that was used as a baseline for this VSM study is more often than not in the awaiting parts category.

Only recently the LRU shops have been authorized to attempt cross-cannibalization actions with other end-items that are already in the shop AWM. These actions are not always successful

and are only attempted if convenient, but the philosophy is that it is easier to get the LRU that is on the test stand working instead of putting it in AWP waiting for a SRU the technician can readily get off another unit. This works in some cases, but in the case of the MLPRF where most failures are associated with the same two SRUs, this effort may be futile and more frustrating. The MLPRF has two specific components that typically fail, the Low-Noise Assembly (LNA) and the Receiver, so cross-cannibalization is usually ineffective and a waste of resources, but it is still attempted. In all instances, the technician will check for SRU availability with the SSC before conducting cannibalization actions, and must get approval from the shop supervisor before commencing such actions. CANNing only becomes an option if the technician has; (1) another end-item available in the shop that is unserviceable, (2) checked for SRU availability with the SSC, (3) determined that the SRU will not be available in the immediate future, and (4) received approval from the shop supervisor and all proper paperwork has been established. These steps would replace step 7 above in the End-Item Repair VSM Time Line table.

Table 3.8: Cross-Cannibalization Success VSM Time Line

Action	Time to Accomplish	Cumulative Time	VA, NVA or NVAE
1. Technician and SSC PMT determine no serviceable replacement SRUs available → Becomes a part of step 6 and 7 above	10 min	10 min	NVAE
2. Technician Locates Unit to Cannibalize from and gets approval from Shop Supervisor	10 min	20 min	NVAE
3. Technician Removes SRUs from CANNed unit	5 min/item	30 min (2 SRUs)	NVAE
4. Technician Places CANNed SRUs into Original Unit in work on test stand → Replaces Step 8 above	5 min/item	40 min (2 SRUs)	VA
5. Technician Reruns Failed Tests to Ensure new SRUs are indeed serviceable – time varies/test (Step 9 above)	5-20 min	55 min	VA
6. If Tests Passed, then Unit Considered Serviceable and handled accordingly to Step 10 in End-Item Repair VSM	5 min	60 min	VA

The repair technician completes the paperwork for the failed SRUs as above, however, instead of serviceable SRUs being ordered against the original WCD number, they are ordered against the end-item that the SRUs were cannibalized from. Of course, this is considering the

cross-cannibalization action was successful in assembling a serviceable end-item. Even though a serviceable end-item is produced through cross-cannibalization, it is unknown whether or not the end-item will fail sooner than if it received a refurbished SRU. Also, cannibalization, while effective in the short-run, can have long term consequences in decreased Mean Time Between Failure (MTBF), and by hiding a possible root cause parts supportability problem.

However, "effective" cannibalization is not always the case, so the technician is forced to place the end-item in AWP status until the backordered SRUs arrive in the SSC standing inventory. Cross-cannibalization is determined to not be successful if the tests the original end-item was failing continue to fail upon retest. Similar to the original end-item repair VSM, each test is run again it the first retest fails. This takes twice as long than if the first retest was passed. It also requires the cannibalized SRUs to be removed from the original end-item and be put back with the cannibalized end-item for later documentation. The technician then generates tags to turn-in failed SRUs from original end-item and inputs the WCD documentation into DRILS and DMAPS as an AWP status and not as a serviceable end-item.

Table 3.9: Cross-Cannibalization Failure VSM Time Line

Action	**Time to Accomplish**	**Cumulative Time**	**VA, NVA or NVAE**
1. Retest after Cannibalization continued to fail → Canned SRUs bad as well → Retest run twice for each SRU replaced, so processing takes longer → Replaces Steps 5 and 6 Above for Cross-Cannibalization VSM	25 min	65 min	NVAE
2. Remove CANNed SRUs from Original LRU and put back with CANNed LRU for later documentation	5 min/item	75 min	NVA
3. Generates tags to turn-in original failed SRUs and inputs WCD documentation into DRILS and DMAPS for AWP → 1577 (NRTS Tag), 350 (Reparable Item Processing Tag)	15 min	90 min	NVAE
4. Move AWP LRU and Failed SRUs to SSC PMT for further processing and placement in AWP Storage Area	5 min	95 min	NVA

The other course of action, aforementioned, is placing the items in an AWP inventory until backordered SRUs are received by the SSC. Upon an unsuccessful cross-cannibalization attempt, the now AWP end-item and failed SRUs are moved to the SSC PMT for further processing and physical placement in the AWP storage area. Also, the PMT handles the tracking and updating of the AWP inventory located within the SSC. Their actions would replace steps 9 and 10 in the end-item repair VSM. There is usually no forecast of how long it will take to acquire all the serviceable SRUs to complete the end-item's repair, which causes variability in the shop flow days of the end-items. Therefore, as the SRUs arrive, they are matched with the respective end-item WCD number that they were ordered against. Once all needed components have been acquired, the end-item is moved back into the repair shop for repair completion and testing.

Table 3.10: Awaiting Parts VSM Time Line

Action	**Time to Accomplish**	**Cumulative Time**	**VA, NVA or NVAE**
1. If item not available, order request attached to specific LRU WCD and S/N for future backorder match-up → Replaces Step 9 and eliminates Step 10 in End-Item Repair VSM	10 min	15 min	NVAE
2. When backordered SRU arrives, brought directly to PMT for processing → Matches form 1348 to AWP log (End-Item WCD Number matched with SRU) → If waiting for more than 1 SRU, then SRU placed with End-item ordered against → Sometimes SRU moved to other item only awaiting single SRU to move more items out of AWP → If only waiting for this SRU, then LRU moved from AWP to AWM to be pulled into LRU shop for repair → Carefully coordinated through PMT AWP log-books and RINM Screen of DO35K, AWP Status and Location → Worked in Batches as SRUs usually arrive in batches to SSC	5-10 min/item	35 min	NVAE

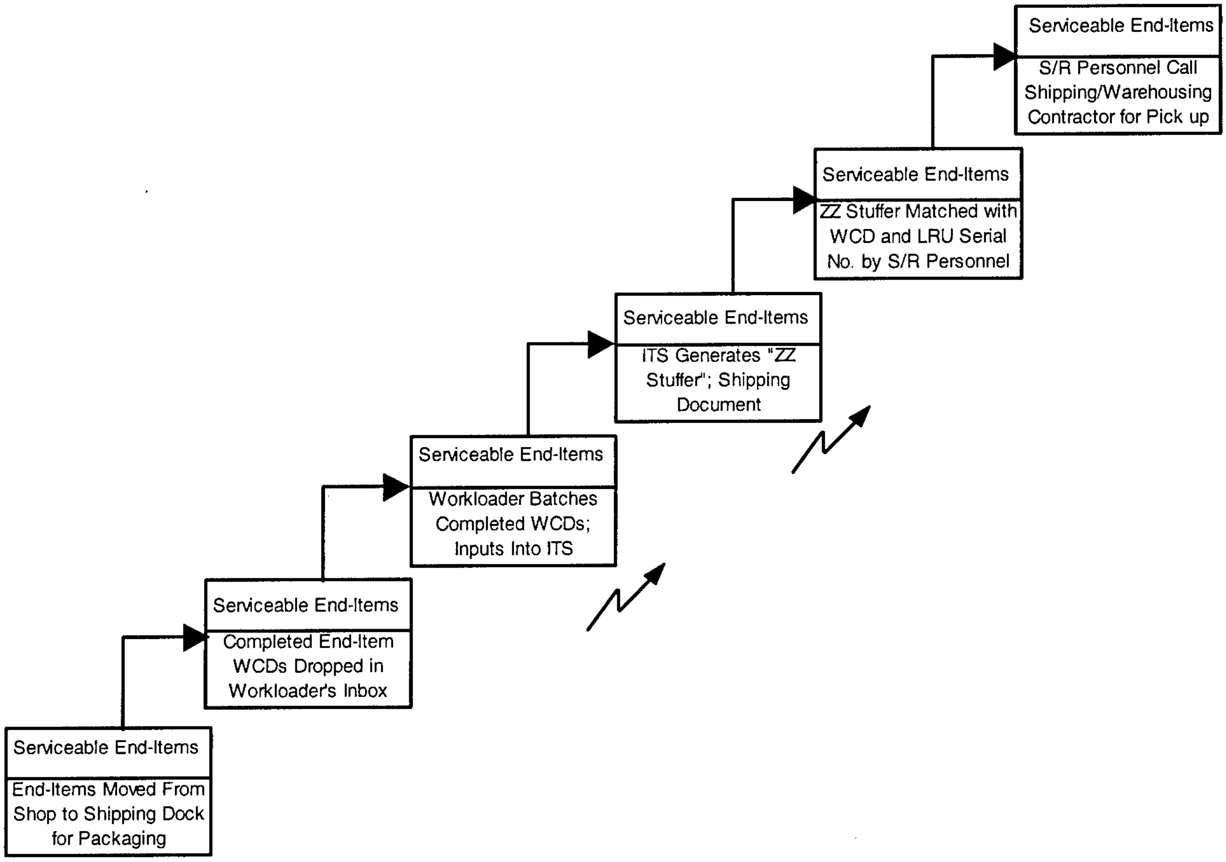


Figure 3.21: Serviceable End-Item Documentation and Movement to CSI

Once repair is completed and a serviceable item is moved back to the SSC S/R area, regardless of the actions taken in the depot repair shop, the workload manager batches the WCDs located in their inbox and enters the WCD number into the Inventory Tracking System (ITS). This movement of end-items from being repaired to being "sold" is captured in figure 3.21. By entering the WCD into ITS, repair is considered complete, and an end-item is added to the serviceable inventory or distributed to an open requisition. This also allows the MMTL to track the number of days each end-item was in depot repair status based on the time of issuance of the inventory tracking number the workload manager received to generate the WCD. ITS also generates a "ZZ –Stuffer", which is a shipping document that informs the depot shipping/warehousing contractor of where the item is to be stored or distributed to fill a requisition. The workload manager verifies that the shipping documentation matches the WCD information then hand-carries the shipping document to the SSC S/R area for match-up with the

end-item. Once all documents and end-items are verified and correct, the SSC S/R personnel contact the depot shipping/warehousing contractor to pick-up the end-items.

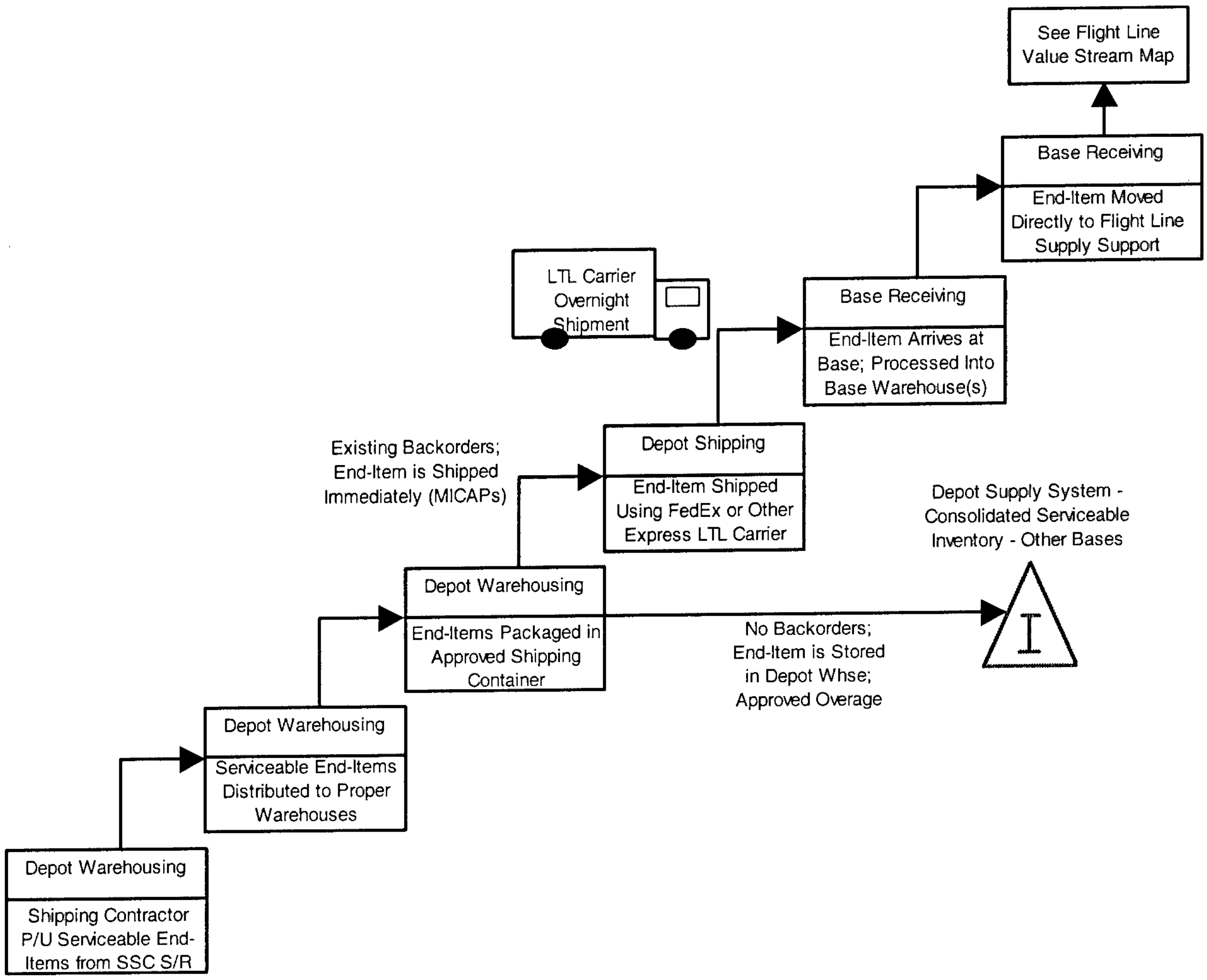


Figure 3.22: Serviceable End-Item Moved into CSI or Filling Base Requirement

The redistribution of serviceable end-items to the CSI, figure 3.22, relies on the depot on-base contractor Again the time before pick-up varies according to end-item priority, with MICAPs having the highest priority, but is typically within sixty minutes of contacting them. The depot shipping/warehousing contractor is responsible for packaging the end-items in accordance with regulations and contacts LTL shipping companies for pick-up of end-items from depot warehouses. The length of time that item stays in the depot warehouse varies greatly depending on Readiness Based Leveling (RBL) stock and demand levels. For high use items, the serviceable assets are usually distributed directly to the bases for immediate use or short-term

storage. For low use items, the serviceable assets may be stored in the depot warehouses managed by the contractor.

Table 3.11: Serviceable Asset VSM Time Line

Action	**Time to Accomplish**	**Cumulative Time**	**VA, NVA or NVAE**
1. Workloader Removes Completed WCD from Inbox and logs Document Number into Inventory Tracking System (ITS) → Generates "ZZ Stuffer" (Turn-In Shipping Document); Ensures Stuffer Matches WCD Information	2 min/WCD	10 min	NVAE
2. Walks ZZ Stuffer(s) to SSC S/R (Batched)	5 min	15 min	NVA
3. SSC S/R Matches Stuffer with End-Item Serial Number → Depends on amount of End-Items	10-15 min	25 min	NVAE
4. SSC S/R Calls On-Base Contract Shipper to Pick-up End-Items from SSC S/R → Time to Pick-up Varies depending on Priority of End-Items (MICAPs highest)	30-60 min	55 min	VA (Wait NVA)
5. Delivery to Depot Warehouse for Packaging	30 min	125 min	NVAE
6. End-items packaged → MICAPs first, then in order of priority → Could sit overnight (16 hours) if dropped off close to 1630 hours	1-16 hours	245 min (2 hrs avg assumed)	VA (Wait NVA)
7. End-item picked up by LTL Carrier	< 24 hours		NVAE
8. End-item delivered to base supply by LTL Carrier	< 24 hours (MICAPs)		NVAE

Once a serviceable end-item is moved back to base supply the avionics sustainment system completes its closed-loop. A specific end-item serial number does not go back to the same base that turned it in, except by coincidence, but fills requisitions by priority and within each priority listing, requisitions are filled on a first-in first-out basis.

3-4-2 Depot Repair, Testing and Supply Value Stream Map Observations:

When end-items are shipped from the bases to depot repair, regardless of direct NRTS or attempted RTS end-items, they follow the same process through depot testing and repair as presented in figure 3.23. Once serviceable end-items are produced, depending on whether or not there are outstanding requisitions, the end-items can be shipped directly back to a base for

immediate use or can be stored in the CSI. The CSI can be located at depot or base supply warehouses, which are used as regional distribution centers by the RSS. The entire depot repair process depends largely on new, serviceable piece part and SRU availability. The sustainment system gets extremely bogged down when parts are not available and the end-items need to be put into an AWP inventory until replacement parts are acquired. Therefore, the VSM task time assumes that all parts are available because the length of time an end-item is in AWP status varies greatly.

At the time of this VSM exercise, the MLPRF had 262 individual carcasses in AWP status. Of these 262, 201 had been in AWP for less than 90 days. Also, 203 of these MLPRFs were awaiting the Low-Noise Assembly. During the actual mapping process, 22 of these AWP carcasses became "parts supportable" when the same number of LNAs were delivered to the SSC. An example of the waste associated with AWP inventories is that the value of these 262 carcasses totals \$83.2 million dollars, \$306,778.77 per carcass, not including the amount of expended man-hours associated with these end-items. Putting this extreme case of waste aside, the depot VSM task time breaks-out into the following; VA, 234 minutes; NVAE, 126 minutes; and NVA, 390 minutes.

Similar to the ATS and base supply VSM task time, a great deal of NVA time is associated with waiting due to on- and off-base carriers. Although the generalized sustainment system does not take into account supply and transportation's part in moving serviceable and unserviceable end-items from base to depot and back, it accounts for a great deal of the time involved. Overall, about 295 minutes, of the 390 NVA, are wasted in waiting for on- and off-base carriers. The other NVA time is associated with the manual movement of paperwork and end-items from SSC shipping and receiving to the workload manager and to the repair shop. Also, there is NVA time in the fact the workload manager must over-induct items to account for the shop's two-shift operations, but only one-shift on-base shipping/warehousing support.

The task time labeled as NVAE is again associated with the entering of information electronically into several information systems as identified in the next chapter. Also, the actual unpacking of end-items from their respective shipping containers has been identified as an NVAE task. Upon repair completion, the end-item carcass is cleaned, labeled and repackaged, which is also considered NVAE because it does not make the end-item more or less valuable.

The depot testing and repair process also adds the greatest amount of value to the sustainment system, by actually testing unserviceable end-items and repairing them to be serviceable. The task time is based on the MLPRF, which takes anywhere between 90 to 120 minutes to test and repair with typical failures. The depot shop is actually allowed 26 hours to repair an MLPRF based on an average repair time, which takes into account the time it took to test and repair AWP and NFF end-items. The process of ordering and acquiring replacement SRUs and piece parts was also considered value added because without this process nothing would get repaired. Also, by ordering the SRUs, an entirely separate SRU sustainment system is put into motion to ensure a steady supply of serviceable SRUs to the depot repair shops. While this SRU sustainment system is outside the scope of the end-item VSM, it is important to consider supplier integration, organic and contract, in the F-16 avionics sustainment system.

3-5 Overall Avionics Sustainment System Value Stream Map:

The value stream mapping of the avionics sustainment system has revealed areas were waste exists, either through waiting, over-production, and/or duplication of effort. Possible improvements to the F-16 avionics sustainment system are recommended in later chapters that could be used in other sustainment systems. Additionally, in the process of developing this VSM it has become apparent that there have been tradeoffs made between Next Higher Assemblies (NHA), and their piece parts. NHAs can be as complex as entire aircraft or as "simple" as the SRUs. For example, with over 200 end-items in AWP status, the MLPRF still only had three MICAP, priority one backorder, requisitions. This would indicate that there is an extreme overage in end-items to compensate for an inept or unresponsive piece parts and/or SRU supply system. Likewise, this could be extended to the F-16 fleet as a whole. With mission capability hovering around 70 percent, but required missions are still being accomplished; is there an overage of aircraft to compensate for an unresponsive structural, avionics, hydraulic and engine sustainment system? Recommendations and conclusions presented in later chapters of this thesis attempt to answer this question.

Finally, to recap the VSM task time for the entire, standard, avionics sustainment system the following is a value added break-out; VA, 407 minutes (28%); NVAE, 427 minutes (29%); and NVA, 642 minutes (43%). Therefore, assuming parts are available and no additional tasks, such as cannibalization or AWP inventory are encountered, the sustainment system should process a

single end-item in 1,476 minutes, not including LTL shipping time. This equates to just over 24 hours of hands-on work in taking an unserviceable end-item and making it serviceable. With the additional shipping time, the entire sustainment system should take about three to four days to complete the closed-loop. There is definitely room for creating more value in the F-16 avionics sustainment system as will be demonstrated in a conceived, future VSM of the system.

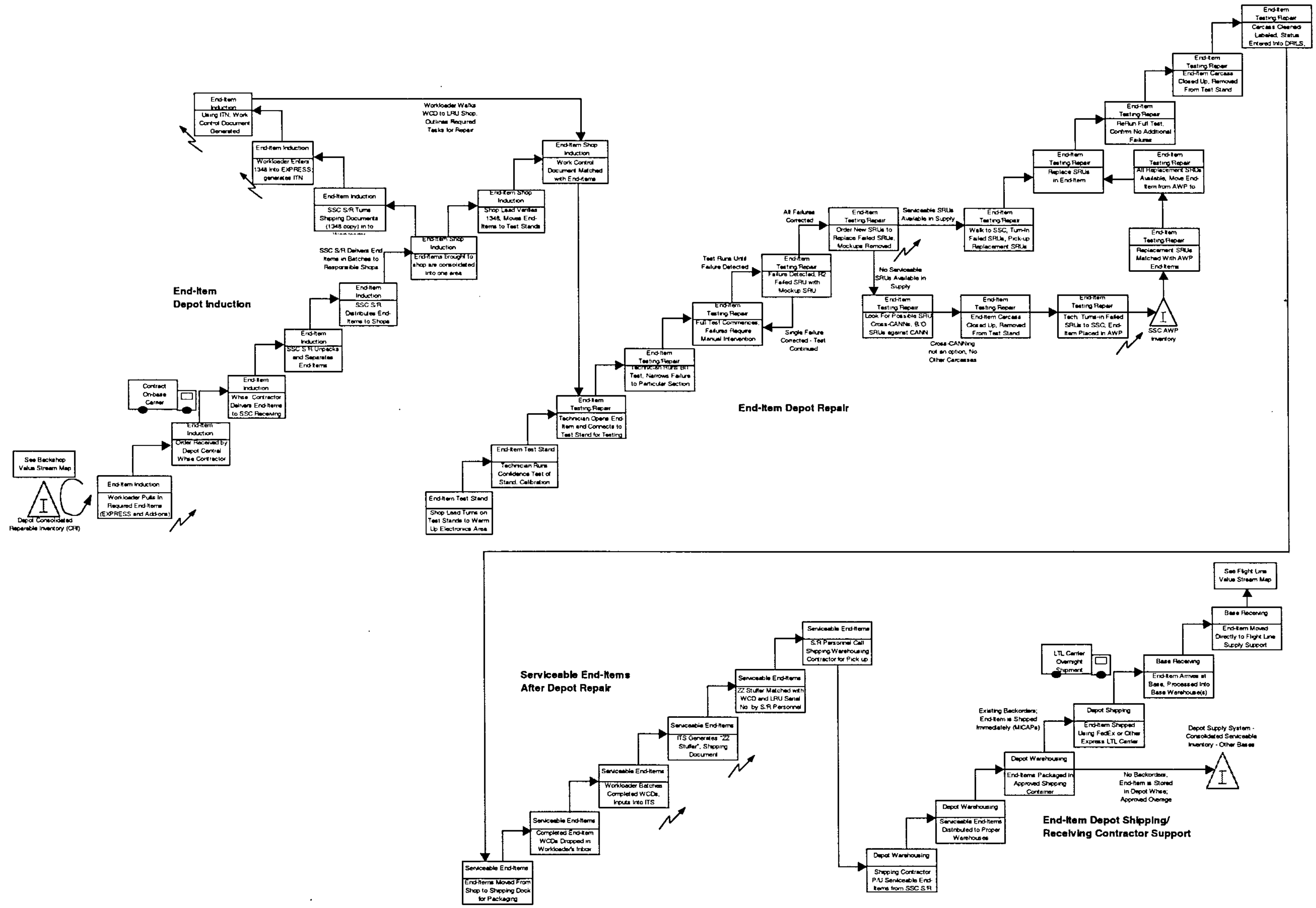


Figure 3.23: Depot Repair, Testing and Supply Value Stream Map

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Chapter 4: Influences on the Sustainment System

4-1 Introduction:

In order to provide a complete analysis of the avionics sustainment system enterprise, it is necessary to examine how the system is influenced by public policy. These policies could act as constraints to the system as it exists presently, and barriers to the system's lean transformation. Policies in the Air Force set forth the organizational, financial, information technology, and regulatory structures in the sustainment system. By understanding the underlying policy structure behind the value stream mapped processes, a lean transformation could be accomplished across the entire enterprise, in hopes of not creating a single "island of success" in the sustainment system. Islands of success are those areas within the enterprise that have had successful lean transformations, but have been unable to diffuse this success to other aspects of the enterprise. By incorporating the entire enterprise into this analysis, a lean transformation will not only diffuse through this enterprise, but because of the integrated sustainment system the Air Force operates, the success should spread to the larger Air Force sustainment enterprise. The Transition-To-Lean Roadmap "pays particular attention to strategic issues, internal and external relations with all key stakeholders, and structural issues that must be addressed during a significant change initiative." (Murman, p.156)

The Air Force Instructions (AFIs) define the organizations and their responsibilities, the financial structure and the information systems architecture necessary to support the sustainment system. The chapter starts with an overview of the AFI policies and regulations that are brought together under process improvement initiatives in order to influence the operation of the avionics sustainment system. The organizational influence, and respective policies, establish the boundary of responsibilities of each organization involved in the system, and highlight the organizational interactions observed during this research. The financial policies define the various complex financing principles that are involved in the sustainment system, and how they are used to the benefit and detriment of the sustainment system. Finally, the policies outlining the information technology systems identify some of the key systems used in the sustainment system and how they may or may not interface to provide the desired system information visibility.

4-2 Policy and Regulatory Influences:

The policies and regulations that directly address the avionics sustainment system are referred to as Air Force Instructions. These instructions are established at the Air Force-level by the Deputy Chief of Staff for Installations and Logistics, Directorate of Maintenance (ILM). These AFIs are supported by more specific Major Command (MAJCOM) instructions. For example, key instructions to depot maintenance are AFI 21-129 and Air Force Materiel Command Instruction (AFMCI) 21-129, the latter of which provides detail and direction to the Depot Repair Enhancement Process (DREP). These two instructions would be better referred to as policy and procedures documents because they establish the policies governing the sustainment system, as well as outlining the procedures for enacting these policies. AFI 21-129 governs the movement of end-items along the entire sustainment pipeline, while AFMCI 21-129 governs the movement, interactions, and processes the depot employs to move end-items through the depot sustainment pipeline. These instructions are not established autonomously for each military service, but are directed by the Department of Defense, which follows Title 10 United States Code (10 U.S.C.) as established by Congress.

4-2-1 AFI 21-129 Two-Level Maintenance and Regional Repair:

This AFI has implemented the Air Force Policy Directive 20-3, Air Force Weapon System Reparable Asset Management. The overall objective of Air Force Logistics, as defined by AFPD 20-3, "is to maximize operational capability by using high-velocity, time-definite processes to manage mission and logistics uncertainty in-lieu of large inventory levels," which should result in shorter cycle times, reduced inventories (both end-items and piece-parts) and cost, and a smaller mobility footprint for movement into combat areas. (AFPD 20-3, p.1) This policy directive outlines the Air Force's logistics goals of the reparable end-item sustainment system. Reparable end-items are referred to as "exchangeables" because a failed unit is typically exchanged for a serviceable unit for essentially no cost to the flying unit. Reparable is also used synonymously with unserviceable in describing an end-item that has failed in its operation. One goal is to "improve the operations of the reparable/serviceable sustainment pipeline." (AFPD 20-3, p.1) In order to accomplish this Air Force logistics operations employ the following actions: (AFPD 20-3, p.1-2)

1. Time definite transportation from home station or deployed site to and from the depot or other source of repair.
2. Expedited DLA processing of reparable end-items to the depot repair shop and serviceable end-items to the bases/installations.
3. Expedited evacuation of reparables by bases and deployed units to the source of repair.
4. Improved timeliness and scheduling of shop repair processes, including repair on demand for both organic and contract repair.
5. Improved contracting for bit and piece support for both Air Force and DLA-managed items.
6. Improved visibility of assets throughout the pipeline.
7. Effective automated monitoring/measurement tools to provide feedback on pipeline operations.
8. Integrated bandwidth efficient logistics information systems to ensure a seamless flow of logistics management and business data.

Even greater direction is provided in AFI 21-129 as to the implementation of two-level maintenance in order to achieve these goals and objectives. AFI 21-129 dictates that failed end-items must be moved off-base within 48-hours of their removal from the aircraft or the requisition of a serviceable end-item from the serviceable inventory, which ever comes first. This is commonly referred to as the "exchangeables" program, and the depot relies on this system to keep flying units from holding onto reparables. The base maintenance units previously held onto an end-item in order to cannibalize as many useful parts out of it to make serviceable units of their own. However, this program aims to keep a predetermined amount of end-items needing repair in the consolidated reparable inventory from which to make serviceable end-items. This is explicitly stated in the AFI as: (AFI 21-129, p.8)

> All 2LM coded LRUs are to be moved off the base/installation within a standard time of two working days/48-hours. The start clock is when Base Supply issues a replacement LRU to the requesting maintenance activity or the maintenance activity removes the 2LM LRU off the weapon system, which ever occurs first. The stop clock is when the carrier picks up the 2LM LRU. If a unit is deployed and transportation channels exist, the unit will make every effort to meet the two-workday/48-hour standard. Customers will use either standard depending on their current automated information system capability to measure pipeline times.

Essentially, the flying unit is charged an exchange price for an end-item, LRU, when it is ordered from base supply by flight line supply support. For the MLPRF, the exchange cost is $38,134.98 as of 1 November 2002. If the failed end-item is turned-in before the 48-hour deadline, the base is reimbursed the exchange cost. Otherwise the base may have to explain why

it was unable to move the end-item off-base in the required time before it is reimbursed. The consequences the base faces if they do not turn in these items within 48-hours is not explicitly stated in the AFI, but is most likely established by the MAJCOM leadership. This system is used to ensure an uninterrupted flow of items through the sustainment pipeline.

The exchangeable system helps to ensure that 2LM can be accomplished with little or no degradation in mission capability of Air Force aircraft. "There are several Air Force logistics concepts and strategies upon which 2LM depends." (AFI 21-129, p.10) "Their main purpose is to develop and improve the pipeline processes, causing less reliance on inventories, ensuring a sufficient flow of items to and from units/installations, and deployed units." (AFI 21-129, p.10) "These concepts are: (1) High Speed Processes, (2) Right-Sized Inventories, and (3) Asset/Item Visibility Tools." (AFI 21-129, p.10) These concepts are synonymous with lean thinking principles, but the Air Force seems to not be meeting the aggressive goals it has set for itself. GAO report 99-77, outlined in Chapter 2, highlighted this point exactly. The Air Force is not achieving its logistics response time goals as established by the Agile Logistics program. Therefore, this VSM and identification of waste and barriers to a lean transformation are key in helping the Air Force achieve the goal of improving the operations of the reparable/serviceable sustainment pipeline.

4-2-2 AFMCI 21-129 Depot Maintenance Management, DREP:

This policy instruction moves from the high-level Air Force focus to a closer focus solely on depot repair operations and its supporting institutions. The Depot Repair Enhancement Process (DREP) is the "standardized AFMC repair process used for all depot level exchangeable repairs." (AFCMI 21-129, p.5) Its objective is to "provide responsive, effective customer support, and improve depot efficiency." (AFMCI 21-129, p.5) However, the last part of this statement may impede the first objective of customer support. The depot repair shops have become more concerned with shop efficiency than their support of the customer. This is because that is how their performance is measured. It seems to have been forgotten that the depots will not always operate efficiently especially during peacetime. The reason is that the depots need to be prepared to support wartime and increased operations tempos with little or no time delay. Therefore, it would be expected that the depot carry more personnel and capacity than is required under normal circumstances. The key tenets of DREP are: (AFMCI 21-129, p.5)

- Standardized repair process (reduced flow days).
- Focus on throughput (constraint management).
- Daily repair based on greatest Air Force need (D087 EXPRESS).
- Supply support on the shop floor (Shop Service Center (SCC)).
- Standardized functions - defined roles and responsibilities.
- Alignment of responsibility/authority of key players.
- Standardized data systems.
- Customer driven performance measures.

Five of these eight tenets are addressed further for greater explanation of their impact on the sustainment system. First, is the tenet of standardized repair processes to reduce flow days. (AFMCI 21-129, p.5) This is important because the entire sustainment system relies on a responsive depot repair process. For example, the standard number of flow days for an MLPRF is five days. However, there are a number of MLPRFs that sit in AWP inventory for much longer than this standard flow time. Data provided by the Inventory Tracking System indicated that the average amount of time an MLPRF spent in depot repair is about 80 days. This may not be accurate because some end-items were in AWP for over 400 days, but nonetheless indicates that the actual flow days is more than five. This is further evidenced by the number of end-items currently in the AWP status. They are measured as less than or more than 90 days in AWP. Currently there are 61 units that have been in AWP status more than 90 days. However, such a measurement may be more meaningful if the distribution was calculated as a less/more than the standard flow days. This would provide greater focus on what the actual number of flow days is for requirements definition, and more expressly demonstrate the effect that parts shortages have on the sustainment system.

The second tenet of interest is that the "daily repair is based on greatest Air Force need as established by the EXPRESS." (AFMCI 21-129, p.5) This has two flaws. First, the prioritization rules EXPRESS employs for repair and distribution are different and inconsistent. (Bozdgoan (1), p.10) Second, EXPRESS fails to represent either a *"pull"* or *"push"* logic for managing the DREP, which exhibits a lack of coherence in the fundamental depot repair strategy. (Bozdogan (1), p.10) Also, EXPRESS is better as a constraint management tool and not necessarily providing actual demand from flying operations. EXPRESS is explained in greater detail later in this chapter.

The third tenet to be addressed is that of placing "supply support on the shop floor in the manner of the SSC." (AFMCI 21-129, p.5) This is a very important and positive aspect of DREP. By moving supply support closer to the repair source there is a reduction in the waste of time spent to acquire the piece-parts necessary to repair end-items. However, this role is diminished by another aspect of DREP, which is that production is only allowed to " request parts early in the repair process, and only the parts necessary to complete repairs will be ordered", rather than in advance of repair. (AFMCI 21-129, p.33) This limits the amount of piece-parts the SSC can have on-hand to support depot repair operations, and impacts the flow of end-items through the depot repair shops if the SSC does not have an appropriate quantity on-hand. Early ordering is near impossible in the case of avionics, where the failed components are identified at the same time as repair. Further complicating the matter is that suppliers take a certain amount of time to produce the SRUs being requested; this can cause delays in receiving piece-parts to complete repairs. This lead-time can be considerably longer than the standard flow days for an end-item and thus impacts aircraft mission capability.

The fourth tenet of "standardized data systems" is non-existent in the sustainment system. (AFI 21-129, p.5) In the course of conducting the value stream map, there were several data systems that were in use at the different levels of the sustainment pipeline. Therefore, this is one goal of DREP that has not been achieved on the depot level or on the larger scale of the Air Force sustainment system. EXPRESS offers some standardization, but the various individuals involved with depot repair interface with two or more systems. These are the Standard Base Supply System, Inventory Tracking System, and in the case of Ogden ALC, Depot Repair Information Local Server, to name a few.

The fifth tenet this research is concerned with is "customer driven performance measures." (AFI 21-129, p.5) This tenet is extremely important in the context of lean thinking. However, the customer in DREP is not only the flying operations, but it is mainly the Supply Management Activity Group (SMAG). The SMAG is comprised of the material managers that determine which and how many end-items are to be repaired by depot repair on a quarterly basis. The SMAG's relationship with depot repairs is explained in more detail in the next section.

The final regulatory influence established by AFMCI 21-129 that concerns this research is that of the "exchangeable induction policy." (AFMCI 21-129, p.38) Depot repair, also referred to as the Depot Maintenance Activity Group (DMAG) is considered to be self-sustaining.

Therefore, the DMAG is required to recoup all costs through the sale of end-items to customers and receipt of payment from those customers to close the transaction. (AFMCI 21-129, p.38) This also establishes the SMAG as the primary customer to depot repair. In addition, SMAG, along with the Defense Logistics Agency (DLA), are the main sources of supply for the repair parts DMAG needs to refurbish end-items. (AFMCI 21-129, p.38)

4-3 Organizational Structures:

The examination of organizational policies is important in identifying the interactions between the numerous organizations that make up the avionics sustainment system. These include; aircraft maintenance unit, flight line supply support, avionics test station, base supply, on-base transportation, the shop service center, depot repair shops, and contract LTL carriers. The main focus of this section is on the organizations that have a direct stake in the repair of avionics end-items, but it is acknowledged that on- and off-base transportation plays a key role in the length of time an end-item is in the value stream. All organizational responsibilities are established in Air Force Instructions (AFI) or Major Command (MAJCOM) Instructions. For example, AFI 21-101 governs base aircraft maintenance organizational procedures at both the flight line and backshop levels, while Air Force Materiel Command Instruction (AFMCI) 21-129 governs depot maintenance organizational procedures and responsibilities. Figures 4.1 and 4.2 provide organizational charts at the base and depot level as they pertain to the sustainment system.

4-3-1 Aircraft Maintenance Units:

The AMU is a part of the Aircraft Maintenance Squadron (AMXS), of which there is usually only one AMXS per wing of aircraft, and it operates under the Wing's Maintenance Group. The AMXS encompasses all flight line and backshop maintenance. The AMU has several sections responsible for different parts of the flight line maintenance mission. The sections outlined in the VSM are crew chiefs, avionics specialist, and supply support. Others include debriefing and scheduling sections, which indirectly support the sustainment process. (AFI 21-101, p.51)

The crew chiefs are the individuals that meet their assigned aircraft upon landing, fix any discrepancies and prepare the aircraft for the next mission. Each aircraft usually has at least one crew chief assigned to it. (AFI 21-101, p.56) This provides continuity in understanding the maintenance history of any aircraft by an individual, so they will be readily able to identify repeating or recurring problems with the aircraft. The crew chiefs work closely with the specialist section in maintaining their aircraft. When a crew chief recovers their aircraft and an avionics discrepancy is annotated, they have an avionics specialist work with the pilot in troubleshooting the problem. There is a lot of teamwork between the crew chiefs and specialists.

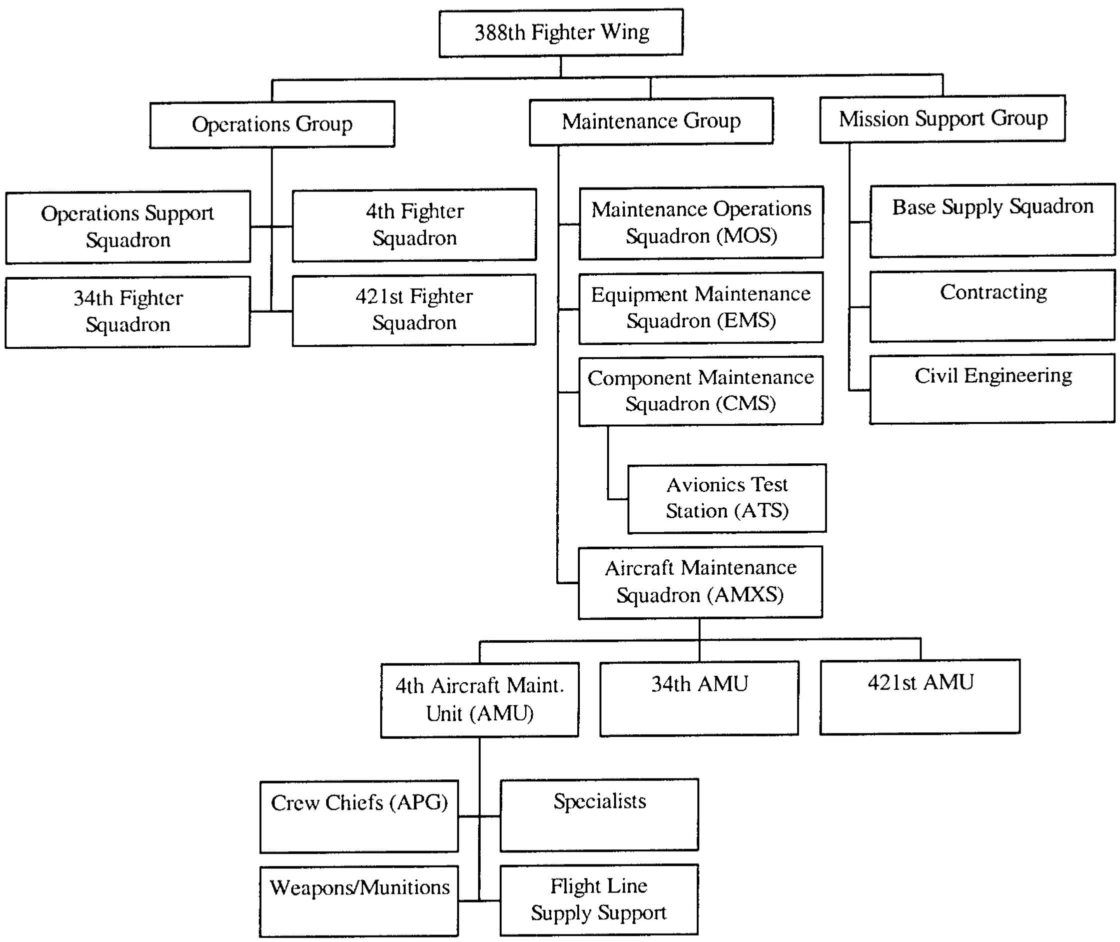

Figure 4.1: Typical Fighter Wing Base-Level Organization Chart

The avionics specialists provide expertise in avionics repairs including the associated wiring, software and LRUs. (AFI 21-101, p.57) There are also specialists in propulsion, hydraulics and

electro-mechanical systems. (AFI 21-101, p.57) These specialists also provide support for Phase Inspections, which are flying time driven aircraft integrity inspections. The avionics specialists have the following responsibilities as stated by AFI 21-101. These responsibilities are:

- Ensures awaiting parts (AWP) for the low altitude navigation and targeting infrared for night (LANTIRN) pods are transferred to the sensor section for cross-cannibalization in support of unit production.
- Performs reprogramming of avionics systems as required by applicable mission directives, PACER WARE/SERENE BYTE messages, or TCTO requirements.
- Maintains guidance and control systems.
- Maintains communication and navigation systems including inter-phone cord repair. (AFI 21-101, p.58)

The final integral part of the sustainment system is the flight line dedicated supply support. Supply support requisitions parts, and uses supply computer interfaces to determine end-item availability. (AFI 21-101, p.67) They also keep maintenance leadership informed of all back-ordered parts, as well as processing the priority-one backorders, MICAPs, in the MICAP Asset Sourcing System (MASS) controlled by the RSS. (AFI 21-101, p.67) Supply support can also upgrade, downgrade and cancel MICAP requisitions. (AFI 21-101, p.67) They track and process DIFM assets, while maintaining the aircraft TNB assets stored within the support section. (AFI 21-101, p.67) They also "monitor the squadron CANN program and associated documentation." (AFI 21-101, p.67)

The supply personnel support the aircraft repair efforts by locating, acquiring and distributing replacement, as well as failed, end-items. They also act as an interface between flight line maintenance and backshop maintenance. Supply assists the crew chiefs and specialists in ordering replacement end-items or initiating the cannibalization of end-items that may not be immediately available in the serviceable inventory. The supply leadership also briefs the AMU leadership of MICAPs and other backorders as well as status on aircraft cannibalization actions.

The crew chiefs, specialists, and supply personnel work closely together to "get aircraft flying" at, what seems to be, all costs. The supply personnel do everything they can to get a replacement end-item to the aircraft in as little time as possible. However, there is little to no communication between AMUs located as the same base or different bases. They consider their tasks independent of other AMUs, and the AMU leadership determines what actions will be taken in specialized cases of MICAP end-items.

The AMU leadership operates somewhat autonomously within its boundaries. Each AMU is responsible for updating the AMXS commander on high-priority maintenance and personnel issues. However, the day-to-day operational decisions are made by the AMU leadership. The crew chiefs, specialists, and supply personnel have a senior representative that informs leadership of tasks being undertaken and recommends actions for the leadership to decide on. For example, cannibalizations need to be authorized by the Production Superintendent (Pro Super), whom is the immediate leadership interface with aircraft repair operations. However, the Pro Super is required to brief his decisions at a daily leadership meeting to ensure everyone is informed of these cannibalization actions. There is no change in power and influence between the crew chiefs and specialist, but the crew chief does have oversight authority of the maintenance conducted on his or her aircraft. The avionics specialist honors their authority and works closely with the crew chief to ensure all discrepancies are addressed.

The flight line maintenance personnel have historically had a great deal of freedom in getting aircraft in the air. This includes the authorization to cannibalize end-items from aircraft to cover supply shortages until a replacement part can be received from the regional supply squadron or depot consolidated serviceable inventory. These are known as "convenience" cannibalizations, and seem to be *accomplished without regard of system-wide impact*, unless an end-item is readily available in the serviceable inventory.

In fact, the 388th FW, the wing observed in this research, actually has a revolving inventory of "CANN aircraft" that they rotate through a designated "CANN-dock"; this process is more common than not at other fighter wings. These are usually the same aircraft that are out-of-service for Phase Inspections. Sometimes the CANN aircraft is an arbitrary aircraft that is out-of-service due to other unscheduled or scheduled maintenance. As long as the paperwork is accomplished properly, ensuring a demand for the required end-item is generated, *there is little concern on the part of all parties involved for the long-run impact continuous cannibalization will have on an aircraft fleet*. The implicit and explicit goal of the AMU is to have as many aircraft mission capable as possible *each day* for flying operations, without concern for long-term effects of this practice.

Continuous cannibalization, while effective in the short-run, can have long-term consequences. It requires a duplication of effort, which involves even more personnel in accomplishing a single repair. An end-item is removed and replaced at least twice for each

cannibalization effort, with little regard to the additional man-hours it takes to accomplish these tasks so long as aircraft are flying. This does not account for the amount of times an end-item is damaged upon cannibalization or the reduced MTBF of a non-refurbished end-item, which can increase the total amount of removals per flying hour.

The *cultural tendencies* of flight line operations and maintenance drive the AMU to do whatever is necessary to meet the flying schedule established by the operations squadron. This invites a fast-paced, high-stress environment that requires each repair be accomplished in as little time as possible. Therefore, the AMU relies heavily on having end-items in stock for immediate repair and cannot wait for supply to get the end-item to them in a couple days; therefore, encouraging cannibalization to fill in the inventory holes.

4-3-2 Base Supply and Avionics Test Station:

The ATS is a part of the Maintenance Squadron (MXS), which is another organization under the Maintenance Group. The MXS consists of personnel from various specialty codes organized into flights: propulsion, avionics, test measurement and diagnostic equipment, accessory maintenance, aerospace ground equipment, fabrication, armament systems, maintenance, and munitions. (AFI 21-101, p.68) The ATS falls under the responsibility of off-equipment (aircraft) avionics maintenance flight.

There is typically only one backshop Avionics Test Station (ATS) responsible for supporting an entire wing of aircraft. The ATS has limited responsibilities due to two-level maintenance (2LM) policies and procedures outlined later in the regulations section of this chapter. Under 2LM, the ATS is only allowed to conduct screening tests to keep "Cannot Duplicate" (CND) end-items out of the reparable inventory. The ATS is effective in catching end-items that may have been failing on the aircraft, but the end-items still operate within set parameters as tested on the IAIS test stands. These are otherwise known as CND type errors. ATS personnel interact directly with flight line supply support, for receiving end-items into the shop, and base supply, for moving serviceable and unserviceable end-items out of the shop. The ATS does not interact directly with the flight line avionics specialists although they share the same Air Force Specialty Code (AFSC). An AFSC denotes the amount of training in particular career fields that an individual has received.

There is an obvious separation between the flight line and ATS avionics specialists. However, these individuals can be easily moved from one to the other depending on manning requirements and career progression. The ATS filters failed avionics into the depot repair system by testing items that may be failing on the aircraft, but meet the parameters set forth in the testing software. In cases such as these, the items are returned to the base's serviceable inventory, and the flight line informed that there may be a failure elsewhere in the aircraft. The ATS operates autonomously from the flight line although they fall under the same maintenance group. The term backshop explicitly denotes the fact that they are not involved in the daily on-aircraft repair, but only the repair of off-equipment end-items.

The ATS personnel are limited in their capacity because they are not able to repair end-items in their shops. During the course of this research they expressed that they feel powerless in the "grand scheme" of the avionics sustainment system. They conduct an important task in keeping CND end-items out of the depot repair cycle, but feel they do not contribute to the overall repair of failed end-items. The shop interacts on both ends of its VSM with supply organizations, and has little chance to pass along any information they have garnered from testing the end-items.

Base supply handles a multitude of items from aircraft structural parts to avionics, hydraulics, engines, and landing gear. There are dedicated supply personnel at the base level to support flying operations. However, they are merely concerned with moving items in and out of "their hands" as efficiently and effectively as possible. There is little reason for base supply to hold onto avionics end-items other than to wait for a shipping contractor to pick up the end-items for movement off-base or to an on-base warehouse.

Base supply dictates how fast or slow items are moved to the depot or back to base warehouses. They are governed by AFI 21-129, under 2LM, to almost immediately ship MICAP end-items coming from the ATS to depot repair and testing. However, in most cases they hold onto items until a full shipping pallet is assembled for more economical shipping to the depot consolidated reparable inventory.

4-3-3 Depot Repair, Testing and Supply:

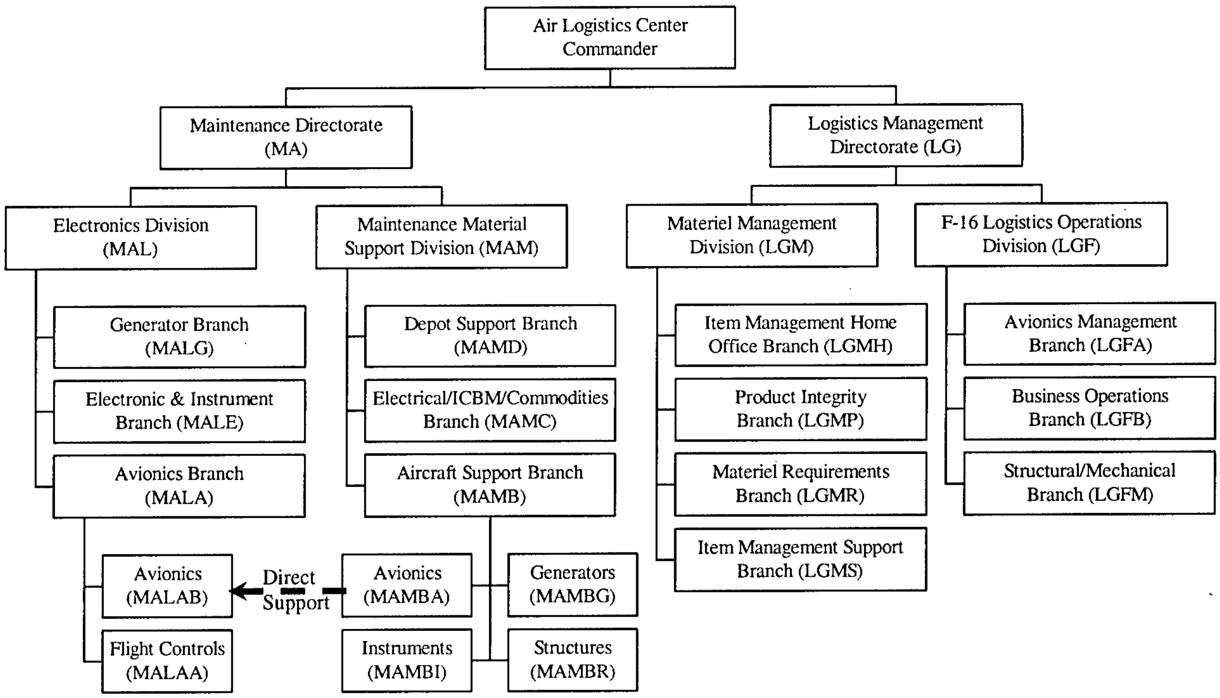

Figure 4.2: Depot-Level Sustainment System Organization Chart

There are numerous organizations, both directly and indirectly involved in the testing and repairing of end-items. It is at these interfaces that the sustainment system seems to break down, and where the most room for improvement exists. These organizations, involved with F-16 depot sustainment, are organizationally separated, and in most cases, geographically separated across a large Air Logistics Center (ALC). In addition, there is a customer-supplier relationship established between the organizations at the ALC as established by the Depot Repair Enhancement Process (DREP) regulation. To further complicate the system, the use of contractors for the inbound and outbound shipping and receiving, as well as depot warehousing, requires a contracting organization to change processes and improve performance.

The supplier organization at the ALC is referred to as the Depot Maintenance Activity Group (DMAG), and is responsible for providing serviceable end-items to its customer. The customer organization is called the Supply Management Activity Group (SMAG), and is responsible for providing the DMAG with their requirements. Also, the SMAG in most cases is the supplier of end-item LRU carcasses, and piece-part SRUs for the repair of these end-items. Until recently the SMAG also controlled the induction of end-items into depot repair through the SSC, but a

recent reorganization of the Air Force moved all maintenance related tasks under one organization. An important example of this move in the VSM is the SSC moving from the Logistics (LG) Directorate (SMAG) to the Maintenance (MA) Directorate (DMAG) to provide direct and indirect materiel support to the depot repair shops.

The SSC involved with the F-16 avionics repair is a part of one division, MAM, and the depot avionics shops make up another division, MAL. For example, the MAL division chief maintains oversight of the negotiated quantities of end-items, but relies on the SSC to induct the proper quantities. In this respect, it is a great team effort and everyone's goal is to get serviceable end-items out-the-door and to the warfighter. However, when money becomes scarce, the tendency is to induct end-items that the shop knows it can repair quickly and sell to bring in more income. This is important in keeping production up, to justify the number of personnel employed and provide a steady workload for the avionics shops.

Both MAM and MAL work with the LG Directorate that consists of the F-16 Supply Chain Manager (SCM) to determine quarterly requirements and negotiated repair quantities. The required quantities are determined by the SMAG Material Managers and the MMTLs, whom are a part of LG, and have little interaction with the shops other than negotiating repair quantities. If the negotiated quantity is less than the forecasted requirements, then the MMTL can authorize the use of a contractor to make up the difference. However, the MMTL typically knows if the depot shops negotiated below actual production capability, so that they can easily meet and surpass the negotiated quantities.

This process loses sight of the main drive of the avionics sustainment system, that of supporting the flying operations customer. The required repair quantities are determined by historical usage and demand data, as well as future flying hour projections. It is suggested that an increase in flying hours usually results in increased requirements or surges in times of war. These two data points as well as other information on recent modifications and system improvements that help determine the required repair quantity, but every SCM believes, "The Forecast is Always Wrong". Therefore, improvements in this interaction and possibly greater warfighter involvement could improve these interfaces.

4-4 Financial Policies:

The avionics sustainment system is driven by several financial systems. The first is the flying-hour program that pays for the direct and indirect operations and maintenance of aircraft at base level. The second is the Depot Maintenance Business Area (DMBA) financial system that is used to fund the repair of unserviceable end-items and SRUs, as well as the acquisition of piece-parts to make serviceable end-items and SRUs at the depot level. These two systems are explained further below.

4-4-1 Flying Hour Program:

The Air Force Flying Hour Program, as established in AFI 11-102, "consists of the flying hours necessary to train aircrews to safely operate their aircraft and sustain them in numbers sufficient to execute their core tasked mission." (AFI 11-102, p.3) "The Air Force Flying Hour Model (AFFHM) provides the methodology and processes that MAJCOMs use to build their flying hour programs." (AFI 11-102, p.3) This model "determines the number of flying hours needed to attain and maintain combat readiness for all aircrews, test weapons and tactics, and fulfill collateral requirements." (AFI 11-102, p.3)

The flying hour program also acts as a vehicle by which MAJCOMs can reimburse the flying units for each hour flown. The flying units contract with the MAJCOM for a certain number of hours each year, based on the Flying Hour program, and the MAJCOM provides them a budget based on the projected cost of flying those hours. For example, in fiscal year 2002, an F-16 wing received $1,832 per flying hour for depot-level reparables in support of the flying mission. They also received $519 per flying hour for consumable items. There is also a flying hour reimbursement for aviation fuel, but this is beyond the scope of this research. These figures are determined by the Air Force Cost Analysis Improvement Group (AFCAIG). The AFCAIG determines what the "official" hourly operational cost will be to operate each Major Defense System (MDS), in this case the F-16. The official amounts are published in AFI 65-604. The Air Combat Command (ACC) receives funding for the F-16 at a set rate by the AFCAIG. Then ACC uses historical data and numerous inputs from base reports to fund each wing at the level they executed the previous year. The executed flying hours are reported to ACC by the wings on a monthly basis, and ACC uses this data to re-flow funding and hours to the units in mid-July of the execution year. (Brandt (1), p. 3)

4-4-2 Depot Maintenance Business Area:

The Depot Maintenance Business Area (DMBA) is a "working capital or revolving fund account" used to fund approved depot maintenance. (AFMCI 21-111.p.2) It is used to finance both organic, Air Force, and contract depot level maintenance operations by "providing initial working capital and allowing recovery of operating costs through the sale of products or services." (AFMCI 21-111, p.2) The AFI also defines depot maintenance as:

The overhaul, conversion, progressive maintenance, modernization, modernization-conversion, interim rework, modification, repair, regeneration, storage, and disposal of aircraft, missiles, target drones, engines, accessories, components, and equipment. A common term used to describe this process is "production." (AFMCI 21-111, p.2)

The Defense Business Operations Fund (DBOF) is the revolving fund (a collection of all DoD revolving funds) that provides a business management structure under which both customers and suppliers are aware of total costs of goods and services. (AFMCI 21-111, p.2) This cost visibility not only enables customers, MMTL or program office, to seek the best service at the lowest price, but also encourages suppliers, depot production, to offer services at the lowest costs to remain competitive and viable. (AFMCI 21-111, p.2) The basic fundamentals of the fund could be a source of contention in the operation of depot maintenance. The most alarming notion is that the seller, production, negotiates with the buyer, MMTL, to "fully workload" depot maintenance capability. (AFMCI 21-111, p.2) This leaves little room for surge capability if the depot workload is operating at its capacity under normal operating conditions. Secondly, the Defense Working Capital Fund (DWCF) establishes a buyer-seller relationship to facilitate the sale of depot goods and services. (AFMCI 21-111, p.2) However, it does allow depot production to focus on the efficient and effective repair of aircraft and end-items, since the customer (SMAG) develops all depot maintenance requirements and obtains the financial authority to pay for the work ordered from the seller (DMAG). (AFMCI 21-111, p.2) The DWCF encapsulates all the military services, so a more Air Force specific explanation of this fund is presented later in this sub-section.

The depot shops act as contractors to the customer in their agreement to producing negotiated quantities based on shop capacity, and personnel availability. The customer orders the negotiated work from the DMBA, which in-turn funds the project orders (PO) that are used for

all organic work ordered and completed. The DMBA initially pays for the work completed and then recoups the funds from the customers as a result of progress billing to replenish the DMBA working capital or revolving fund. The DMBA is controlled through the AFMC workload planning, programming, and budgeting systems, and the analysis of key business area financial documents. (AFMCI 21-111, p.3) The objective of depot maintenance, as stated in AFMCI 21-111, is to "efficiently workload and fund organic capability." (AFMCI 21-111, p.3) The budgeting system serves as a "baseline for determining that DMBA sales rates and prices are adequate to offset expenses, as well as the correct type and volume of sales are being planned, and planned expenses for each cost element are consistent with current management policy." (AFMCI 21-111, p.4)

The progress billing allows the depot shops to "get paid" for each end-item that is returned to the CSI as a serviceable unit. Serialized workloads, such as end-items with requirements, are billed at the approved sales rates times the number of hours reported as being completed. (AFMCI 21-111, p.4) This gives an incentive for depot repair to produce what can be easily produced, and not produce end-items they are encountering problems with, such as parts availability. This allows depot repair (DMAG) to recoup some of the losses it experiences when items are not parts supportable, and are then moved to AWP status.

The DWCF is further identified to each respective service, and the Air Force managed fund is the Air Force Working Capital Fund (AFWCF). (AFMCI 21-129, p.58) These are further broken down into Air Force and AFMC managed activity groups. (AFMCI 21-129, p.58) The group that oversees depot maintenance is the AFMC managed SMAG and DMAG as highlighted earlier in this section. These organizations are used in the financial management aspect of depot operations, but this has a profound affect on how depot repair operates since funding continues to be an important constraint. The SMAG is made up of the "Materiel Support Division (MSD), General Support Division (GSD), and Fuels." (AFMCI 21-129, p.58) The MSD is "responsible for the management of the wholesale inventories that are held and sold to customers." (AFMCI 21-129, p.58) These wholesale inventories are made up of unserviceable and serviceable end-items and components (SRUs). They are sold from the SMAG to customers, such as flying operations, and the income is used to maintain inventory through depot repair or procurement actions. (AFMCI 21-129, p.58) The GSD is "responsible for consumable piece-parts, bulk items,

and expendable end-items managed by the DLA, General Services Administration, and locally purchased." (AFMCI 21-129, p.58)

As expressed before the DMAG provides repair services to the SMAG, and bills the SMAG for these services an agreed upon price. (AFMCI 21-219, p.59) Payment is only received at the completion of a maintenance task, thus the DMAG operates at a loss until end-item repair is completed. (AFMCI 21-129, p.59) However, the DMAG must operate within a "burn-rate" as established by EXPRESS with inputs from the SMAG. The burn-rate expresses how fast the depot is spending its yearly budget. This allows the DMAG and SMAG to identify funding shortfalls or cost overruns by which production is influenced. This relationship, while financial in nature, outlines some of the organizational boundaries and buyer-seller relationship that occurs between two organizations located at the same ALC, but with separate agendas in the sustainment system.

4-5 Information Technology Systems::

There are countless information systems used by the various organizations in the avionics sustainment system. Four of those systems will be highlighted here as having the greatest direct involvement in the sustainment system; their use is outlined in the previously identified policies. These are the Standard Base Supply System (SBSS), the Execution and Prioritization of Repair Support System (EXPRESS), the Inventory Tracking System (ITS), and the Depot Repair Information Local Server (DRILS). Information technology systems are extremely important in the support of a 2LM and Agile Logistics in the Air Force. A lack of information visibility or quality can severely hamper the depot repair enhancement process, and cause the sustainment system to not support the right customer requirements.

Each system will be discussed in terms of the information it requires from, and provides to the system. The overview of these systems is not meant to be all inclusive because all of these systems are very complex, and have modules that do not relate to the sustainment system.

4-5-1 Standard Base Supply System:

The SBSS is an accounting system that provides base activities with their supply needs and accounts for supplies, equipment, fuel, munitions, and clothing. (AFMCI 211-29, p.81) It allows

personnel to track every item in the Supply System through standardized programs and procedures. (AFMCI 21-129, p.81) The SBSS database stores common item and financial records for supply, and accounting and finance functions, in order to provide information pertaining to supply management, appropriation, general ledger, expense, and financial inventory accounting. (AFMCI 21-129, p.81) However, the sustainment system interfaces with SBSS on a much more rudimentary level through basic transactions. These basic transactions include filling issue requests, requisitioning items when there are not enough in stock to fill requests or maintain stock levels, processing items, handling backorders and shipments, and taking inventory. (AFMCI 21-129, p.81)

During the value stream mapping, SBSS was used to gather information on the MLPRF. Information on such things as carcass cost ($306,778.77), exchange cost ($38,134.98), average repair costs ($24,401.70) were current as of 1 November 2002, and available for accounting and finance. The inventory aspect of the system provides the authorized base level for an item, the number of current demands the base has, and the base's demand for the last 0-6 months and 7-12 months for a particular item. SBSS order placements act as an indicator to pull a serviceable item from the consolidated serviceable inventory, but rarely enacts a pull process in the depot unless there are no end-items in the serviceable inventory. It also starts the Due-In-From-Maintenance 48-hour clock for the exchangeables program if a serviceable end-item is furnished to the aircraft maintenance unit. SBSS has an array of practical application, and easily provides information pertinent to the sustainment system. This system is used by supply personnel at all levels, flight line, base and depot, and provides each with specific information that pertains to each level.

4-5-2 Execution and Prioritization of Repair Support System:

The primary purpose of the Execution and Prioritization of Repair Support System (EXPRESS) is to "use weapon system operating requirements and readiness targets as the driver for prioritizing repair and distribution of assets, and to identify constraints affecting the repair process." (AFMCI 21-129, p.77) It also determines the order in which repair should be done. (Mathaisel, p.8) The overall objective of this system is to support the DREP process described earlier in this chapter. (Mathaisel, p.9) Also, it has sub-objectives which support the overall objective. These sub-objectives are: "(1) identify customer needs, (2) prioritize needs for repair

and distribution, (3) assess repair supportability and identify constraints, and (4) trigger automatic introduction of reparables into repair." (Mathaisel, p.9)

EXPRESS represented a major advance over previous information systems designed to manage the depot-based component repair process. (Bozdogan (1), p.2) EXPRESS operates on a daily basis by pushing into the depot repair shops those items determined to be priorities in the constrained depot repair environment. It makes these determinations by examining customer needs (demands) and the repair environment using current asset and resource information. (AFMCI 21-129, p.78) "EXPRESS measures carcass, parts, capacity and funds against predetermined criteria", as stated in AFMCI 21-129, as well as "identifying repairs for programmed Depot Repair Enhancement Process (DREP) workload." (AFMCI 21-129, p.24)

If any one of these criteria is not met or the end-item is not part of the quarterly programmed workload, then they are not pushed into the depot repair shops. However, the workload manager, with approval from the material manager, can manually intervene in the EXPRESS process to induct end-items. These inductions may or may not coincide with the daily demand being generated by the base level flying operations. It is likely that "EXPRESS may not be able to meet either one of two critical challenges: (1) enabling the performance of component repair on-demand ("pull" system), or providing an effective means of providing forecast-based repair services ("push" system). (Bozdogan (1), p.2) Additionally, the various modules that make up EXPRESS "seem disconnected, data-intensive and cumbersome, in addition to suffering from poor data quality." (Bozdogan (1), p.2) Therefore, the DREP quarterly requirement process, while grounded in data from the operating units, loses sight of the customer's actual demand when the material manager dictates what should and should not be repaired by the depot shops. This further exacerbates SMAG's ability to forecast customer demand, and DMAG's ability to repair the end-items that would provide the greatest improvements in mission capability. It is important to state that all those involved in the requirements determination and repair of end-items strive to support the customer, but the policies and procedures outlined in AFMCI 21-129 impede this process, and cause the supplier-customer disconnect.

EXPRESS should be used as a guideline in making tough constraint prioritization decisions, but the customers' actual daily demand should pull end-items into repair in order to maintain predetermined stock levels as required under Readiness Based Leveling (RBL). RBL is designed to allocate worldwide inventory among bases and depot to reduce base expected backorders. It

also ensures that the stock levels do not exceed the required amount calculated in the Recoverable Consumption Item Requirements System and controlled by the material manager.

4-5-3 Inventory Tracking System:

The Inventory Tracking System (ITS) is an on-line, real-time computer system that "tracks and manages shop workloads, inducts end-items into the appropriate shops, and tracks the end-items and their sub-assemblies/components through the disassembly, repair, and assembly processes." (AFMCI 21-129, p.80) The system is also used to track and report actual shop flow times for each end-item. (AFMCI 21-129, p.81) The system is extensive in that allows instant visibility of all assets and requirements, and numerous management reports meant to aid in planning workloads, and repair processes. (AFMCI 21-129, p.80-81)

The workload manager used ITS in the VSM to induct end-items into repair. A work control document (WCD) was generated in ITS using the 1348 repair and shipping documentation, and an inventory tracking number obtained from EXPRESS. The WCD had two purposes. First, it moved the inducted end-item out of supply's responsibility into depot repair's responsibility. This allows for accurate tracking of the actual shop flow time each end-item encounters. The second purpose of the WCD is to provide the repair technician with documentation paperwork to put the item in-work status, completed status, and in some cases AWP status in depot repair. It also allows the repair technician a place to manually document which tests an avionics end-item failed, and which components were replaced to generate a serviceable end-item. Once a serviceable end-item is completed, the workload manager moves the end-item from the shop to supply in ITS to stop the flow time clock, and to add one more item to the serviceable inventory. This also generates the proper shipping documentation to move the serviceable end-item into an inventory warehouse or to send directly to a base to fulfill a backorder.

4-5-4 Depot Repair Information Local Server:

The Depot Repair Information Local Server (DRILS) is "a specialized web based application for collection and retrieval of Air Force maintenance information." (TQS brochure) DRILS has the motto "Carpe Datum" – "Seize the Data". (TQS brochure) This suggests that an organization should own and maintain its own data, while still providing data to support legacy systems like EXPRESS, ITS, and SBSS. (TQS brochure) DRILS' goal is to "provide the benefit to those who

enter the data," namely working level shop technicians and leadership. (TQS brochure) It not only allows for easier, quicker data entry, but improves the data's consistency; therefore allowing for accurate historical analysis to all managers in the sustainment system. (TQS brochure) The basic data provided by DRILS is: (TQS brochure)

1. Item identification information, such as national stock number, part number, description, serial numbers, and manufacturer code.
2. Configuration information, such as applicable work codes, and mission design series (using weapon system).
3. Flow time accounting broken down into in-work, awaiting maintenance and awaiting parts status.
4. Information on where the asset was shipped from to provide history of unit interaction. This may lead to discovery of improper procedures at the base or flight line level or failed base testing equipment.
5. Repair information, such as item discrepancies and corrective actions, parts replaced or adjusted, and parts that received other maintenance (re-soldered pins), cannot duplicate items, and quality deficiency reports.
6. Awaiting parts information, such as parts waiting for, and parts arrived to support repair
7. Cost information, such as actual repair and replacement costs for easier calculation of average (standard) repair costs.
8. User information, such as flying unit that turned end-item in for tracking purposes. May indicate that some geographic locations fail items more or less often because of environmental considerations.

Unlike the other three systems addressed in this section, DRILS is a local information technology system used in the depot's F-16 avionics repair shops, and is still in the development phase. DRILS started initially by making information previously documented on the paper WCDs available through electronic media, and is still in a testing configuration. This provided enhanced visibility into information that has long been documented on paper, and filed with no further uses. This enhanced visibility is being continuously expanded to include more and more of the depot repair shops. Also, it has been expanded to base level through testing at the 388th FW, which is co-located with F-16 depot repair at Hill Air Force Base, Utah. The ATS uses DRILS to track the number of failures, and types of failures they are seeing on end-items they test. They are also able to provide this information to depot repair on a limited, testing basis. The depot can gather more information on the actions already taken on an end-item at the base-level, which may reduce sustainment pipeline times if used in a beneficial manner.

4-6 System Influences Summary:

This chapter highlighted the key policies governing the Air Force sustainment system. These policies also contain procedures for enacting these policies in order to standard the sustainment pipeline across weapon systems and the various depot repair operations. These were not meant to be all inclusive, but merely to present those policies with the most direct impact on the sustainment system value stream map. Some of the policies identify the need to have a shortened sustainment pipeline and depend on a very responsive supply system to achieve the goals they set forth. However, it is obvious in the value stream mapping that there are significant policy and regulatory influences that set forth organizational, financial, and information technology conditions that may constrain or benefit the sustainment system. It is these constraints and benefits that are addressed in the waste identification, conclusions and recommendations presented in the next three chapters.

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Chapter 5: Waste Identification

This thesis uses value stream mapping as a vehicle under the Lean Enterprise Analytical Framework to examine an extremely complex U.S. Air Force sustainment system. More specifically it "mapped" the path that F-16 avionics follow from aircraft removal through base repair to depot repair and return to the serviceable inventory or aircraft. The identification of waste in this chapter is based on the types of waste as labeled by lean principles; we strive to create value through flow, pull and perfection to achieve a customer-focused and knowledge-driven enterprise. It is evident, by the tasks outlined in Chapter 2, that there is room for further improvement of the sustainment system by examining the system at all levels; flight line, base and depot. The various sections of this chapter will highlight waste elimination and value creation of the system as a prelude to the overarching conclusions presented in Chapter 5.

There are seven types of enterprise-level waste analyzed in this chapter, which expand upon the "Seven Wastes" developed for manufacturing and identified in Chapter 1. These seven types of waste are: waiting/delays, excessive transportation, inappropriate processing/ineffectual effort, inventory, excessive motion, defects/rework, and overproduction. (Mize, p.4)

5-1 Waiting/Delays:

5-1-1 Flight Line:

The greatest amount of waste generated by waiting and/or delays at the flight line level occurs when serviceable end-items are not available in the local supply system, including end-items available through cannibalization. This requires the flight line supply support personnel to order the required end-item from the Regional Supply Squadron (RSS). The RSS could take up to 24 hours to respond to a request for a serviceable end-item, and require an additional 24 hours for an express LTL carrier to move the end-item from the regional warehouse or other base to the requesting unit. This two-day wait can impact the mission readiness of aircraft because most aircraft cannot fly without their full-compliment of avionics. This waste would dictate that there would be more inventory, which is also a wasteful action. However, customer focus would drive the desire to have a "right-sized" inventory that is responsive and not wasteful.

5-1-2 Base:

Additional waiting is introduced into the system by base supply in the movement of unserviceable end-items from the base to depot. Base supply typically waits to ship end-items to the depot until it has a full-pallet of end-items in order to take advantage of discounts for shipping a larger amount of goods using a LTL carrier. As long as pallet build up does not exceed one day, there would be no impact to the flow of end-items off the base and to the depot.

5-1-3 Depot:

Again the movement of end-items from repair shops to supply generates the largest amount of "waiting" waste. The depot relies on a responsive supply system to move end-items through repair. However, the depot utilizes a contractor to provide all on-base movement of goods, and coordinate all off-base good movements. Thereby, the contractor is free to operate as it wishes as long as it is providing support in the manner outlined in its contract. Currently, it can take up to two days for end-items to be delivered to the repair shops from the time they are ordered by the workload manager. This impedes the depot repair shop's ability to schedule maintenance in an effective manner. It also creates backlogs in the repair shop of end-items awaiting maintenance. This is most evident in the fact that the depot shop operates using two-shifts, while the shipping contractor only operates one-shift during normal business hours. Therefore, the workload manager usually over-inducts items in order to ensure end-items are available for the second shift personnel. This same kind of waiting is seen once repairs are completed as well.

The shop service center (SSC) shipping and receiving dock requests for the contractor to pick-up serviceable end-items, but there is no set length of time that they could reasonably expect to have these end-items moved to the depot warehouse for packaging and distribution. Moreover, the contractor waits for end-items to be picked up by LTL carriers for movement to bases to fill requirements, and to regional serviceable inventory warehouses.

The greatest amount of waiting in the depot repair process is that caused by lack of spare parts. In the case that spare parts, SRUs, are not available to complete an end-item repair, the end-item is placed in an Awaiting Parts (AWP) inventory until these parts are acquired. This creates the greatest disruption to flow, in that it could take up to 90 days or more to acquire the required SRUs. Considering in the case of the MLPRF, the standard length of time an end-item should be in depot repair is five days, a 90 day delay can create considerable backlogs. For

example, at the time this research was conducted in early January 2003, there were 262 MLPRF end-items in AWP inventory. Of these 262, 61 were in AWP inventory over 90 days. Also, 203 of these end-items were waiting for the same SRU. Some of these 203 end-items may also be awaiting more than one SRU, but the majority of the LRUs are waiting for this one item. Considering the daily demand rate of the MLPRF hovers around three, there is about 90 days of supply sitting in AWP, which could be considered work-in-process inventory.

5-2 Excessive Transportation:

There does not appear to be any excessive transportation at the flight line and base level of the sustainment system. However, there is considerable excessive transportation at the depot level that may impede its responsiveness.

5-2-1 Depot:

As end-items move in and out of depot repair, there is a supply process that buffers each side of the actual repair process. Any inbound end-items are received by the depot shipping and receiving contractor and all outbound end-items are packaged and distributed by the same contractor. Inbound end-items are stored in the centralized depot warehouses until requested for depot repair by the SSC workload manager that has authority over these end-items, such as the MLPRF. Excessive transportation is introduced in that an end-item that is shelved, must be removed from the shelf, and moved to the SSC shipping and receiving (S/R) area located elsewhere at the depot. The SSC S/R personnel unpack the avionics end-items and move them to their respective repair shops. Upon repair completion, the end-items are brought back to the SSC for movement, by the contractor, back to the centralized depot warehouses, otherwise known as the Consolidated Serviceable Inventory (CSI). These serviceable end-items are packaged by the contractor at the centralized warehouse, then moved to shelves in the warehouse or moved off-base to fill an existing requirement. In the case that an end-item is shelved, when a requirement is generated, it is moved to the off-base shipping and receiving area and awaits pick-up by an LTL carrier. This is excessive in that instead of storing end-items, serviceable and unserviceable, in a centralized warehouse, requires additional movement when the end-items are requested into the depot repair shops. For example by co-locating unserviceable end-items with the SSC and associated repair shop, the items can be pulled from the inventory as they are

needed instead of having to wait for the contractor, which is on its own schedule, to deliver the end-items.

5-3 Inventory:

Inventory spans the entire sustainment system, so it will be addressed by the three types of inventory that exist in the sustainment system. The first is the consolidated reparable inventory (CRI), and consists of all end-items that have failed on-aircraft, and failed the base screening process. Second is work-in-process (WIP) inventory, which includes awaiting maintenance (AWM) and AWP inventories. Finally, the consolidated serviceable inventory (CSI) includes all serviceable end-items that are not on an aircraft, but are on shelves awaiting the next requirement.

Inventory waste is generated by having end-items remaining in any one type of inventory for a prolonged period of time. While some inventory is necessary to support the uncertainty of demand created during surges in flying operations, wartime and peacetime surges, it can be minimized to afford the greatest benefit. Within the three types of inventory, there are also two kinds of items pertaining to avionics that move through these inventories. First are consumable piece-parts. These "consumables" are parts that are not refurbished at any repair level, but are thrown out when they are replaced. This includes bolts, nuts, washers, wire, and other low-cost parts. It is important to keep adequate amounts of consumable parts available since depot repair does not want to keep a multi-thousand dollar avionics end-item from being repaired because a two-dollar part is unavailable. The second type of items is reparable or refurbished items. These "reparables" actually exist in the two categories, SRUs and LRUs, as explained in chapter 1. Avionics SRUs are smaller components of LRUs, but are repaired in the same manner of testing, repairing and retesting until a working SRU is returned to the serviceable inventory. However, while SRUs are more expensive, thousands-of-dollars, than consumable items, they are not nearly as expensive as the LRUs. LRUs are the end-items that the value stream map followed in this research, and usually cost hundreds-of-thousands of dollars. Therefore, a tradeoff needs to be made between which parts have increased stock levels. If there are not enough consumable parts or SRUs, then the repair of end-items is severely hampered and greatly impacts the flow of these end-items through the avionics sustainment system.

Inventory also refers to the SRUs and piece-parts ordered to support end-item repair. Having piece-parts in the inventory keeps the sustainment system flowing, and eliminates the waste generated by AWP inventories. However, having too much piece-part inventory is a waste in "overproduction". Therefore, it is pertinent to determine the right-balance of piece-part inventory necessary to support the daily repair operations. Having the right parts, at the right place and the right time requires considerable coordination between the workload manager and the retail item managers in the SSC. However, it also relies on an accurate bill-of-materials (BOM) and part usage rates. These are not always available, and thus impede the flow of end-items through the sustainment system.

5-3-1 Consolidated Reparable Inventory:

It is necessary to have some reparable inventory for the depot repair shops to induct for repair purposes. This is natural to the closed-loop sustainment system; end-items need to fail in order to be repaired and moved to the serviceable inventory. However, having too many end-items in CRI may indicate that customer demand is not being met because with each failed end-item, a serviceable end-item is being drawn from the system. Eventually, the system will run out of serviceable end-items if the unserviceable end-items are not inducted for repair.

5-3-2 Work-In-Process Inventory:

This type of inventory is where most waste is found. In the case of the MLPRF, there are at most five end-items being repaired at any one time, on the five dedicated test stands. There may be ten waiting to be tested because they were inducted to compensate for lack of supply support for a two-shift repair operation as explained in section 5-1-3. In the case of the MLPRF, there are more than 262 end-items in the WIP inventory, the majority of which are in AWP status. These AWP inventories create the most waste in the avionics sustainment system.

AWP end-items are not being worked on, and cannot be used by an aircraft because they are unserviceable. Also, they cannot be used by another repair organization, such as a contractor, since the organic depot repair shop has already worked on them. This is established by regulation because the depot repair shops would not recoup the time and money already spent on the end-items if they were moved to a contractor facility. Likewise, the repair shop has already worked on these end-items, but they have not been paid for them, so they have man-hours

invested in these end-items while they sit in AWP status. Therefore, the depot shop operates at a loss for these items until repair is completed and they are returned to the CSI.

The cause for these AWP inventories is the lack of SRUs available for repair. These SRUs may not be available due to any number of reasons; a common one is that a supplier does not exist because the SRU only recently began to fail. Another is that the supplier is providing to few of these SRUs to satisfy demand. Finally, the supplier may be having difficulty obtaining the piece-parts required to repair SRUs similar to the repair of the end-items. This bogs down the SRU supplier, and in-turn affects the flow of end-items through the depot repair shops.

5-3-3 Consolidated Serviceable Inventory:

The CSI has the greatest impact on mission capability of aircraft. However, it relies on the proper placement of serviceable end-items in the sustainment system. The goal is to not have too many end-items in the system because they are expensive, especially in the case of avionics. Therefore, in order to reduce inventory costs, these inventories are kept to a minimum at the flight line and base levels, and sustained at the depot level. As end-items are drawn from the base CSI, end-items are to be moved from the depot CSI to back-fill the end-items drawn from the base CSI. This is ideal if the sustainment system is responsive to customer demand, but CSI levels are not determined by usage rates directly, but by requirements established by a material manager.

Requirements are determined using a complex modeling technique by a material manager that is not directly involved in the sustainment system except to identify quarterly requirements to the depot repair shops. If the material manager forecasts the requirements wrong, it could result in insufficient, or too much, inventory. Understated requirements can have a larger impact on mission readiness and customer satisfaction than overstated requirements. Regardless, the customer focus is lost in this process by moving from what is a daily usage rate to a quarterly demand schedule determined from a forecast. The forecast does consider the daily demand rate, but is only a snapshot of one day of a month multiplied by the number of days in the quarter. In addition, any logistics manager will say "The Forecast is Always Wrong". Therefore, there should be a better way to determine how to "right-size" the CSI.

5-4 Inappropriate Processing/Ineffectual or Duplication of Effort:

Most of the waste generated by inappropriate processing or ineffectual effort is caused at the interfaces between the various organizations involved in the sustainment system. There is also considerable waste that can be considered a duplication of effort as well. Again the waste spans the entire sustainment system, and can be addressed by topic rather than by flight line, base or depot organizational separation.

5-4-1 Manually Generated Forms:

From the time an end-item fails until it is replaced, there are a number of forms that are completed by individuals in order to set the ordering and repair process in motion. The most common of these forms is the Order Request Form, Form 2005. This form is completed by the avionics technician to initiate the acquisition of a serviceable end-item from the CSI, whether it is stored at the flight line, base, regional or depot warehouse. This form also begins the Due-In-From-Maintenance (DIFM) process that drives the flow of unserviceable components into depot repair. DIFM is also referred to as the exchangeables program, where the base has 48-hours to turn-in an unserviceable end-item for an already acquired serviceable end-item, in sense a carcass-for-carcass exchange.

A new Form 2005 is developed by base supply in order to assign a Work Control Document number that is used to generate shipping documentation, Form 1348, to move the unserviceable end-item from the base to its respective depot. The depot workload manager then uses the 1348 to generate an Inventory Tracking Number, which in-turn is used to generate another Work Control Document (WCD) and number. This WCD number is used to generate the final shipping document for serviceable end-items before they are moved into the CSI.

All these systems provide information visibility to various outside organizations, such as material managers, but would benefit from a one-time, one-system "tracking number" generation based on the initial Form 2005 order. Also, in cases where no serviceable end-items are in the local supply system, an automatic inquiry would be sent to the RSS with an automatic response system using intelligent inventory systems to determine best location to ship a serviceable asset from to the requesting unit.

5-4-2 Forms Verification:

At each stage these manually generated forms are verified with the end-item. While each verification takes minimal time, but it can be taxing in instances when there are numerous end-items to verify at once. This mainly occurs at the depot level. Thereby, enacting an electronic system, such as bar-coding of each avionics end-item, the sustainment system could tie together the electronic forms and end-items at each stage of the sustainment system, and eliminate the ineffectual effort put forth to match end-items with forms, and to manually track these forms while in the process.

5-4-3 Manual Supply Inquiry:

The avionics technician at the flight line and the depot repair technician both manually check for parts availability. In the case of the avionics technician, this is an inquiry for serviceable end-items for on-aircraft repair. Conversely, the depot repair technician submits supply inquiries for serviceable SRUs and piece-part availability in the SSC inventory. Both technicians walk from their work area to the supply support function to make these inquiries. This takes the technicians away from their task of primary responsibility, repairing aircraft and/or end-items, and if the items are not available becomes quite a waste of time and effort.

5-4-4 Cannibalization:

There are two levels of cannibalization. One level is cannibalization between aircraft, and the other is cannibalization between end-items. Both are deemed inappropriate processing because it requires completing the same task twice, duplication of effort, in order to achieve the same goal that a single action would accomplish. There is some benefit to be gained from aircraft cannibalization if there are no end-items in the supply system, locally or regionally, and the one additional aircraft is absolutely needed to complete a mission. However, the costs are; completing the same repair twice, maybe more if the original cannibalization was ineffectual, and taking manpower away from other repair or preventive maintenance tasks. Also, there is considerably more coordination and documentation required to complete an aircraft cannibalization

Conversely, end-item cross-cannibalization, typically does not provide any direct benefit to the end user or serviceable inventory. This is evident in the fact that most end-items contain the

same failing SRU or piece-part. An example of this is the fact that of 262 MLPRFs in AWP status, 203 of these require a Low-Noise Assembly to make them serviceable. Therefore, many cannibalization actions do not result in a serviceable end-item, but only duplication of effort.

Also, without parts supportability of end-items, there is significantly more effort involved in moving end-items into the AWP inventory. These efforts include increased tracking of documentation and SRU arrivals tied to specific end-items. In addition, the ineffectual effort of disconnecting the end-item from the test stand only to have to reconnect it to complete repair once all ordered parts arrive for the end-item uses at least twice as many man-hours and degrades the shops' capacity. The shop's capacity is degraded by the loss of man-hours used to perform these cannibalization and AWP end-item actions.

5-5 Excessive Motion:

There is excessive motion at each stage of the sustainment system. Most of this motion is the hand-carrying of end-items and documentation from one organization to another. A great deal of this waste was already addressed in the inappropriate processing/ineffectual effort section of this chapter. Some examples of this excessive motion are outlined in table 5.1.

Table 5.1: Excessive Motion in F-16 Avionics Sustainment System

Flight Line	• Avionics technician walks from flight line (aircraft) to flight line supply support to inquiry on end-item availability then walks back to aircraft to remove end-item while awaiting replacement. • Hand-carrying end-items from flight line supply support to ATS (RTS) or base supply (NRTS).
Base	• Hand-carry end-items from ATS to base supply when NRTS – walked to base supply.
Depot	• SSC S/R personnel hand-carry forms (1348s) to workload manager, and manually move end-items to repair shops. • Workload manager hand-carries WCDs to depot repair shops and matches them with the end-items that were inducted. • Depot repair technician walks from shop to SSC to order replacement SRUs and piece-parts, then returns to test stand with or without replacement parts. • Shop technician moves serviceable end-items from shop to SSC S/R area for movement back to serviceable inventory. • Shop technician drops completed WCD in workload manager's inbox and gives unserviceable SRUs to PMT for documentation and turn-in for DIFM requirement. • If SRUs and/or piece parts not available, end-item moved to AWP inventory (WIP) until replacement SRUs are obtained from supplier.

5-6 Defects/Rework:

There are two types of tasks accomplished in the avionics sustainment system that can be considered rework, or more loosely, defects. These tasks are cannibalization between aircraft and end-items, and the multiple testing of end-items at the base and depot level. Cannibalization could be considered to be affected by defects in the sustainment system. This stems from the thought that it is quicker to cannibalize an end-item between aircraft than it would be to wait for an end-item to arrive from the supply chain. Cannibalization is also accomplished between two or more end-items to make one serviceable end-item. This is caused by the lack of piece-parts and/or SRUs in the supply system, and the notion that it is better to repair the end-item on the test stand than move it directly to the AWP inventory. These are two thought processes that should be changed with a lean transformation.

5-6-1 Cannibalization:

Cannibalization was also characterized as a waste under the ineffectual effort heading of waste. The rework involved in aircraft-to-aircraft cannibalization wastes manpower and time that could be devoted to other tasks, such as additional preventive maintenance. There is also no guarantee that the cannibalization will always be successful. Also, cannibalizing an end-item may make the aircraft mission capable for only one more mission because there is no good gauge, at the time of cannibalization, of how many more missions will be accomplished with the cannibalized end-item. For instance, this end-item may fail after or during the next flight because of rough handling in the transfer, may be close to its mean time between failure, or another aircraft system is shorting out the end-item, to name a few. Additionally, the cannibalization may not be successful, in cases where the cannibalized end-item has also failed or was damaged upon removal, and thus create twice the workload with no positive outcome.

The second level of cannibalization is referred to as cross-cannibalization, and is accomplished between end-items at the depot4. Recently cross-cannibalization was authorized to fill a supply void caused by the unavailability of some key SRUs for MICAP end-items. These efforts require supervision authorization and documentation by the repair technician, and the shop service center PMT. Rework is being introduced by the need to remove the failed SRUs

[4] Note: Cross-cannibalization is only allowed if there are more than one end-item of the same type in the depot shop at same time. End-items are not inducted from the reparable inventory solely to allow for cross-cannibalization.

from the original end-item, as well as removing the SRUs from the end-item identified for cannibalization. In most cases, the same SRUs are failing in each of these avionics end-items. Additionally, without testing the cannibalized end-item, there is no way of determining whether or not the cannibalized SRUs will work in the original end-item. This drives a duplicative effort of removing and replacing SRUs from two or more end-items. These efforts may not produce a serviceable end-item, but rather additional retesting and documentation. In addition, these two end-items will most likely enter the AWP inventory, thus tying-up twice as many man-hours for a varying amount of time. The amount of time an end-item spends in AWP status varies considerably with the receipt of serviceable SRUs and other piece-parts.

5-6-2 Multiple Testing:

As laid out by the value stream map, end-items are tested at two levels in the sustainment system. They are first tested by the Avionics Test Station (ATS) as a screening process to ensure two things. First is to ensure that the end-item is indeed failing in some manner, and second, that if the end-item is not failing or failure cannot be duplicated, flight line aircraft technicians are notified that there may be some other aircraft failure. The ATS screening process tests end-items until they fail their first test. They attempt to reseat the affected SRU and test the unit again. The technician reseats an SRU by removing it then placing it back in the end-item, sometimes removing dust or dirt that may be on the electronic contacts. If the end-item continues to fail, the end-item is immediately removed from the test stand and turned over to base supply for shipment to the depot.

The ATS is only concerned with keeping end-items that are not failing on the test stand out of the sustainment system and in the serviceable inventory. The waste is introduced by the fact that ATS testing does not try to identify more than one failed SRU. Also, there is no visibility by the depot into the test failed at the ATS because it is only documented on the tags accompanying the end-item when it is turned into base supply, and not recorded in any information system. Therefore, this information is lost until the end-item is inducted into the depot repair shop. The depot repair shop is then responsible for running the full set of tests on the end-item, repeating the same tests the base completed. This is considerable rework in the fact that while the ATS keeps "cannot duplicate" (CND) end-items out of the depot sustainment system and in the serviceable inventory, the depot still has to retest the failed end-items once

they are inducted into depot repair. CND end-items are a small percentage of the amount of end-items tested by the ATS.

5-7 Overproduction:

There is very little overproduction in the flight line and base levels of the avionics sustainment system due to the fact that the system is initiated with the turn-in of failed end-items on the flight line and ATS. If an end-item does not fail, it is not put into the sustainment system. The depot operates on a different system of quarterly negotiations and produces end-items to meet these negotiated quantities and not necessarily daily demand as created by the user.

Depot overproduction occurs when there is an over-induction of end-items into the depot repair shops. Over-induction means that more end-items are inducted into depot repair than can be repaired at the same time, and this occurs for two reasons. First is the need to over-induct end-items to account for the depot repairs' two-shift operations, and the lack of on-base shipping contractor support beyond one-shift. This lack of support drives the workload manager to induct more items early in the day to accommodate the two-shift depot repair operation.

The second reason for over-induction is the need to meet negotiated repair quantities or meeting the daily EXPRESS repair demands. In the case of the MLPRF, almost all end-items inducted enter the AWP inventory, and only a few that do not require the most commonly failing SRU are actually able to be repaired. Thus, over-induction is required to ensure that the depot shop is repairing some end-items to meet these two sources of indirect customer demand.

To further illustrate this point, the MLPRF currently has 262 end-items, valued at $317,671.38 each, in AWP inventory (current January 2003). These 262 end-items are essentially overproduction from the standpoint that daily demand is only about three units. Therefore, a 90 day supply of end-items remains unserviceable, tying up depot repair shop man-hours and space, and financial resources. Also, 203 of these items, 77 percent, are awaiting the Low-Noise Assembly (LNA), and each LNA costs $86,723.48. Therefore, a choice needs to made between having more SRUs available, at less cost, in order to keep the more costly, but more crucial, end-items from being tied up in an AWP inventory. Roughly, for each MLPRF in AWP, more than three LNAs could be purchased and kept in inventory for the same value. This kind of trade-off analysis coupled with the use of the daily demand rate does not seem to be accomplished and each end-item demand is determined separately from each other. The lack of

availability of piece-parts adversely impacts the flow of the system, and the fact of not knowing what parts are needed for repairing the end-items until testing is conducted impedes the smooth flow of end-items through the avionics sustainment system.

5-8 Summary:

This chapter highlighted several areas of "waste" in the F-16 avionics sustainment system. The waste identified is that which is visible through this initial value stream mapping of the system. An aspect of implementing lean principles in a system or enterprise is identifying the need for continuous improvement, striving for the ultimate goal of perfection. By identifying these wastes, the system can begin to flow more smoothly, and have more of a customer focus. Several of these wastes are caused by overarching structural inefficiencies that are identified in the conclusions presented in Chapter 5. As these overarching conclusions are addressed, and recommendations are integrated into the sustainment system, more wastes will become apparent, and drive further improvement to the system.

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Chapter 6: Conclusions

The waste identification presented in Chapter 5 provides detail in locating wasteful practices in the F-16 avionics sustainment system. This chapter aims to provide overarching conclusions that can be considered the root causes of the waste and impeded flow in the system. There are four conclusions reached in this research; some apply to the entire sustainment system, while others apply to specific aspects of the system. These conclusions are supported by the information provided by value stream map in of the system in Chapter 3 under the Lean Enterprise analytical framework explained in Chapter 1. Also, several of the conclusions are supported by other research pertaining to sustainment systems presented in Chapter 2.

During the course of this research the depot's process of determining repair requirements changed under a new program referred to as Agile Logistics. This program is a repair-on-demand system and is aimed at "(1) reducing the time required to repair inventory items, (2) reduce inventory levels, (3) match the repair of items with the demand from customers, and (4) rapidly moving items to and from customers." (GAO 99-77, p.16) These conclusions are based both on the observed batch-processing and the introduction of repair-on-demand processing.

6-1 Considerable System Waste:

It is evident that there is considerable waste in the system as highlighted in Chapter 5. The last section of Chapter 3 also highlighted that of the 1,476 minutes (24.6 hours) that end-items are being handled in the standard avionics sustainment system, 642 minutes (10.7 hours), 43%, are non-value added (NVA) tasks. This waste keeps the system from achieving a smooth flow of end-items through the system. More importantly, this NVA time does not include the highly variable time that end-items may spend in an awaiting parts status of work-in-process inventory.

The majority of this system waste is a result of lack of supplier and contractor integration, which is key to fostering a lean enterprise, and one of the four goals of the Air Force's Agile Logistics program. This is most evident in the shipping contractor fully supporting the on-base movement of end-items to the depot repair shops. The end-items are delivered to the SSC S/R areas at random, and could take up to two days. This causes perturbations in the ability of the depot repair shops to effectively schedule end-items in for repair. Additionally, this same type of delay is caused at the other end of depot repair. Once a serviceable end-item is turned into the

SSC S/R area from depot repair, the contractor is expected to pick up these end-items as soon as possible. There is priority given to end-items that have MICAP requirements, but this is still no guarantee of immediate pick-up, packaging and shipment to fill the outstanding backorder. This waste is further compounded for organically repaired SRUs that use the same on-base depot shipping contractor. An SRU may be backordered from the end-item repair shops, but it could take two days for it to be moved as a serviceable asset from the SRU shop to the end-item repair shop because of the need to go through the contractor in order to move these SRUs. No internal system exists for direct movement, and documentation of such movement, of SRUs from the SRU shops to LRU shops, which is adding more waiting time into the system.

Finally, while not under the direct control of the Air Force, there is considerable waste in the time it takes to ship unserviceable end-items from the various regions across the world to the depot and to ship serviceable end-items from the depot to the respective regions in which the F-16s operate. Some of this waste is addressed by having regional repair centers, such as Kadena Air Base, Japan, where avionics end-items are repaired regionally instead of being sent the depot (Ogden Air Logistics Center) at Hill Air Force Base, Utah. End-item inventory buffers are also built in to accommodate for the time it takes to transport end-items to and from the depot. However, there is very little control over how long it actually takes, and the time used in determining proper inventory levels may not reflect the actual transport time. All MICAP end-items are moved using express shipments and typically only take about 24 hours each way. The Air Force relies heavily on these express carriers to help provide the responsive supply system that is important to the mission capability of the F-16 fleet. However, this can be a costly venture especially if end-items are not being inducted immediately into repair, which would render expensive express shipment pointless.

6-2 Customer Focus Lost:

This conclusion directly addresses one of most important aspects of the definition of a lean enterprise as established in Chapter 1. In order to evolve a lean enterprise, flow, pull and continuous improvement become the main tenets of the system in achieving a complete customer focus. Customer focus is also important in the incorporation of the Air Force's Agile Logistics program, by matching the repair of end-items with customer demand. The customer, as established in this research, is the U.S. Air Force units flying the F-16 aircraft such as operations

groups and squadrons. They are supported by their flight line, base and depot maintenance groups and organizations, but the depot repair shops have very little direct contact with the customer. The flight line and base maintenance units collaborate to provide as many mission capable aircraft as possible to the flying operation. They go to great lengths to repair aircraft as fast and safely as possible and provide substantial aircraft preventive maintenance. However, with the highly integrated nature of the sustainment system, they also rely heavily on the support provided by the depot repair shops.

6-2-1 Indirect Customer Relationship:

The depot repair shops[5] have an indirect relationship with the customer (operational units), but a direct relationship with the SMAG which acts as a "go-between" for depot repair and the flying operations. Figure 6.1 demonstrates this relationship. Essentially the SMAG's customers are the flying operations. Meanwhile, the SMAG, as outlined in Chapter 4, acts as the customer to the DMAG[6], which disconnects depot repair from the rest of the sustainment system. SMAG also acts as the depot repair's main source of supply for SRUs, along with the Defense Logistics Agency (DLA) that provides most consumable piece-parts. This relationship is represented in Figure 6.2.

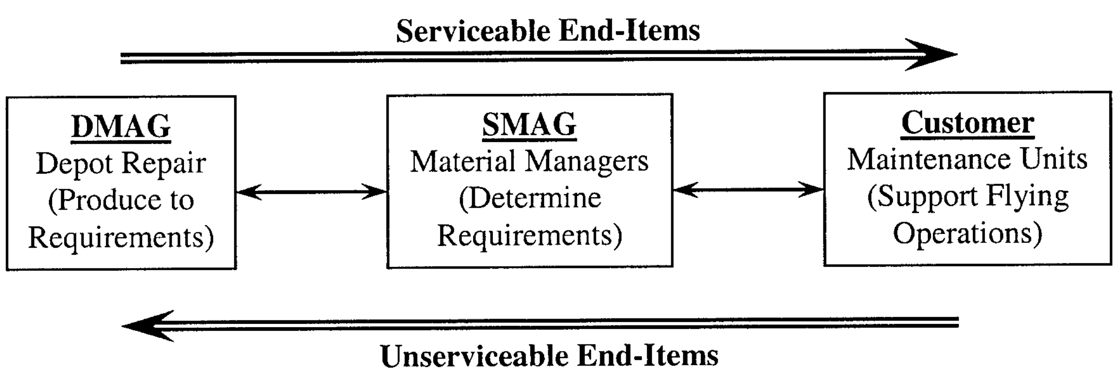

Figure 6.1: Indirect Customer Relationship

[5] The reference to depot repair shops includes their respective shop service centers that are essentially the supply counters for the repair technicians.
[6] Reminder from Chapter 3: The Depot Maintenance Activity Group (DMAG) is the same as depot repair, but is referred to as DMAG in financial contexts as the supplier for the Supply Management Activity Group (SMAG) that

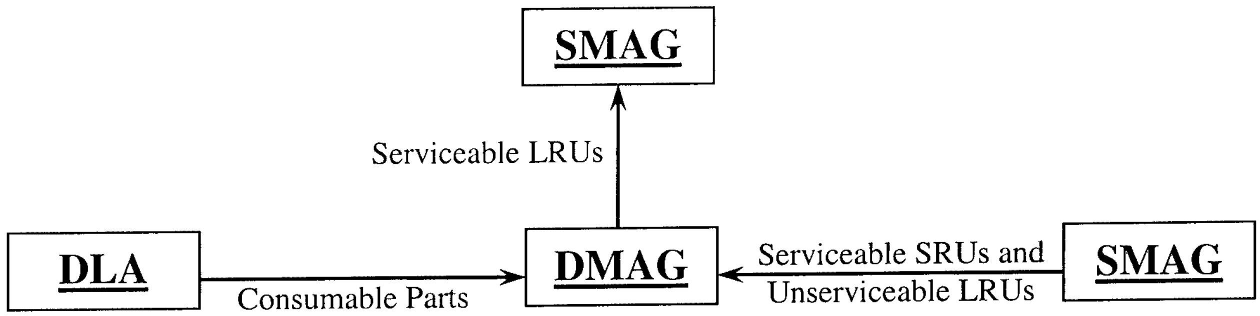

Figure 6.2: Supplier Relationships of Parts and End-Items

Until the recent initiation of Agile Logistics, the material managers operating under SMAG made quarterly determinations as to which end-items and how many are to be repaired based on historical daily demand rates and other information. The Agile Logistics program moved depot repair from a "batch-processing" mentality to more of a "repair-on-demand" operation, eliminating the quarterly negotiations process. Before the implementation of Agile Logistics, the SMAG negotiated quarterly repair requirements with the DMAG to meet the flying units' needs as determined by the SMAG. The negotiation process allowed the DMAG to negotiate lower repair quantities based on capacity, and/or manpower constraints. Therefore, if any requirements are not met, the SMAG can hire an outside contractor to address the shortfall. Unfortunately a contractor typically has no visibility of direct customer demand and will only produce to the contracted requirements. The Agile Logistics program does not address the relationship between depot and base repair, and still required SMAG to make quarterly repair requirement determinations to be used for budgeting purposes, as well as supporting modules for the EXPRESS information system. This keeps the DMAG from fully understanding the operational customers' expectations, and from producing what is actually demanded by these customers.

To further complicate the depot repair system, the Fixer (shop supervisor) ultimately controls what is inducted into repair within the repair requirements. This relationship can become very adversarial with the depot not meeting the forecasted requirements of the SMAG. This is further proof of depot repair's lack of visibility of real customer demand. One final point is that SMAG controls the money paid to the DMAG for repair, and the DMAG is not paid for repairs until a

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includes the material managers and F-16 supply chain manager. The DMAG is self-sustaining wherein all costs are required to be recouped through payments from customers (i.e., SMAG, which acts as the sole customer).

serviceable end-item is generated and returned to the CSI. Thereby, under the Agile Logistics program, the SMAG funds on demand to support the DMAG's repair on demand process.

6-2-2 DREP Performance Measures:

The depot repair shops lose their customer focus even more in their quest to meet their performance measures, otherwise referred to as metrics. These performance measures are established in AFMCI 21-129, and are mainly geared towards financial performance as well as shop production and efficiency. The goal of the Quality Performance Measures (QPMs) is only to provide trend information to managers, and they are not intended to do or drive anything else. These managers, using QPMs, should drive desired actions or behavior based on a defined strategy or action plan. If their plan is to improve shop efficiency, then that is the goal the shop is going to strive for, and will not provide a customer focus as a priority. Additionally, all nine QPM data points aggregate the shops' workload and do not examine each product separately. This aggregation of data may blur the shops' real performance because they may be producing some end-items with ease, while other end-items may be encountering considerable repair problems. Therefore, the shop is inclined to produce more than what is negotiated of the "easy-to-fix items", while producing below negotiated quantities for the "hard-to-fix items" to meet aggregate goals. So long as the goals of the nine QPMs are being met, no further analysis is required. Current performance measures conflict with providing depot repair shops with a customer focus. Therefore, performance measures that stress the importance of a customer focus on supporting flying operations need to be established. Conversely, performance measures focused solely on production and/or financial goals need to have less importance for the benefit of an improved customer focus.

6-3 Repair Parts and Materials Availability:

This section concludes that the lack of spare parts, namely SRUs, to support the repair of end-items also keeps the sustainment system from creating value by flowing end-items through as smoothly as possible. This is most evident by the number of end-items that are in awaiting parts (AWP) status in the depot repair shops. Also, the GAO noted that "inventory problems are adversely affecting customer operations" in the report outlined in Chapter 2. (GAO 99-77, p.20) This impact is demonstrated by the increase in non-mission capable due to supply (NMCS) rates,

and the subsequent decrease in mission capability (MC) rates during the 1990s. The NMCS rate has more than doubled from 6.4%, in 1990, to 13.9%, in 1998, and MC rates have fallen from 84.6% to 74.3% in 1990 and 1998 respectively. (GAO 99-77, p.21-22) Also, an even more telling performance measure is the supply issue effectiveness rate for repairable items on the F-16. In 1997 and 1998 the issue effectiveness rates for all operational F-16 bases were 49.3% and 48.7% respectively. (GAO 99-77, p.26) This means that at least 50% of the time a serviceable part was requested, it was not available in base inventories thus causing non-mission capable aircraft or aircraft-to-aircraft cannibalization.

6-3-1 Evidence in In-Process (AWP) Inventory:

The research reported here, focusing on the MLPRF, used it as a reference for the standard sustainment system, but this end-item is also representative of the AWP inventory process. As of January 2003, there were about 262 MLPRFs in AWP inventory at a combined value of over $83 million, not including the amount of man-hours tied up in this inventory. These MLPRFs are awaiting roughly $23 million in repair parts and materials, mostly SRUs repaired at the same depot. Of this $23 million, $17.5 million is for one SRU, 203 units of the LNA, which is also repaired at Ogden ALC. More importantly, at the same time there were three aircraft that were non-mission capable due to the lack of availability of this end-item in the sustainment system. Therefore, a total of $56.4 million in aircraft, $18.8 million each (constant FY98 dollars) remain on the ground, unable to support flying operations. Therefore, a tradeoff needs to be, or has already been, made to determine what level of piece-part stock is acceptable in keeping aircraft mission capable.

The Air Force aggressively reduced piece-part inventories during the 1990's in its move from 3LM to 2LM and initial implementation of *lean logistics*. The Air Force was counting on a "responsive supply system" to cover the reduced inventories, but it seems that this responsiveness has not yet occurred, and this is impacting mission capability along with a variety of other factors that are beyond the scope of this research. For example, the GAO reports that based on the available the SMAG's average logistics response time (LRT) was 87.5 days for the fourth quarter of 1998. (GAO 99-77, p.42) This is twice as much as AFMC's reported average LRT of 44.7 days for fiscal year 1998. (GAO 99-77, p.34) More important is the fact that AFMC decided financial budgets and inventory forecasts based on a LRT of 9 days. (GAO 99-

77, p.34) This lack of responsiveness, as well as setting an obviously unachievable goal has had considerable impact on piece-part, and serviceable end-item, availability. Air Force headquarters acknowledges that unresponsive repair of end-items is a serious problem and that it has adversely affected aircraft mission capability. (GAO 99-77, p.35) Also, Air Force and DoD officials state "that the AWP problem and backorders are both indications that the supply system is not working as intended..." (GAO 99-77, p.35) This unresponsive system is further aggravated by the reduction in the inventory of repair parts and materials, as well as of new spares, under the *lean logistics* initiative of the early 1990s.

Therefore, tradeoffs need to be made at some level between stocking more piece-parts and generating fewer serviceable end-items, and this can be achieved in a system that smoothly flows end-items through depot repair. It is evident from the Tradeoffs in Air Force Maintenance research conducted by Luis Tsuji in 1999, presented in Chapter 2, that depot repair time has a significant impact on the cost incurred by the sustainment system. Also important, and in support of developing improved flow in the avionics sustainment system, is the impact that depot repair time has on mission capability.

6-3-2 Lack of Coordination Between Repair Shops:

It was also observed that most of the SRUs each depot uses to repair avionics end-items are repaired at the same depot location. In the case of the MLPRF, the number one AWP-causing SRU is repaired in a separate building that is less than 500 feet from where the MLPRF is repaired. The quarterly negotiation process to determine the number of end-items to be repaired in a quarter no longer exists. However, the requirements are loaded into EXPRESS to prioritize repair requirements on a daily basis. In addition, there seems to be no coordination between the LRU and SRU repair shops in determining required quantities of SRUs to support the daily repair rate of LRUs. The daily repair requirements for SRUs are also determined by EXPRESS, supported by quarterly requirements estimates based on historical demand rates. There is some coordination accomplished by EXPRESS to match SRUs to end-items, but it is not clear how this is done or how this is made internally consistent in estimating quarterly repair requirements. Increased coordination between the shops would prove invaluable in providing a steady supply of serviceable SRUs to support the LRU workload.

The SRU shops support more than one repair facility for MLPRF end-items. The SRU shop also support regional MLPRF repair at Kadena Air Base, Japan. The regional facility carries a higher shipping receipt priority than the depot, and receives serviceable SRUs before the depot. While this regional facility provides an important service, the Air Force may be degrading overall F-16 mission capability in order to support one regional facility. By establishing a prioritization scheme, the depot cannot easily determine when it will receive backordered SRUs because the regional repair facility orders will be satisfied before the depot's orders, even though the depot's order was made in advance. This increases the uncertainty of how long end-items will be in AWP status, and/or if end-items will have piece-parts available when they enter depot repair.

6-4 Information Visibility and Quality:

The final conclusion reached is that the visibility and quality of information needed to support a 2LM sustainment system does not fully exist. There are a considerable number of information systems that support the avionics sustainment system as outlined in Chapter 4, but none of the systems currently in use provide a full-picture of the flow of end-items through the system. Each level of the sustainment system uses different information systems. The flight line uses CAMS and SBSS, the base (388th) uses SBSS and DRILS, and the depot uses DMAPS, DRILS, ITS, SBSS, and REMIS as well as several modules of EXPRESS. Also, each of these systems allows the users at each level to enter information. This increases the probability of "dirty data" being entered into either one of these systems. Each level may not use the same systems, but the systems usually interact at some level to provide information. Therefore, dirty data in at one level can affect the output at another level. Also, there is no visibility of where erroneous data may have been entered.

6-4-1 Lack of Information Visibility Impeding Flow:

Information visibility is an important compliment to the avionics sustainment system. Two examples of loss of information visibility in the avionics sustainment system were addressed earlier; testing data from base to depot, and customer daily demand rates by depot repair. By not having an information system that will track testing data from the ATS to depot repair, a duplication of effort is generated. Depot repair then has to retest the same components that the

ATS tested. If the depot were to have the test data from the ATS beforehand, and it was correct, then the depot could pre-order piece-parts associated with the failed tests. By losing this information in the transfer of end-items from bases to the depot, a critical step in the flow of end-items through the system is missed. This type of information could accommodate a Just-In-Time (JIT) delivery of applicable SRUs to depot repair and improve the flow of not only LRUs, but also SRUs.

The second example of non-visibility of the daily demand rate by the depot repair shop is attributed to the loss of customer focus. As defined by policy, depot repair's customer is the SMAG, but its products directly support flying operations. The depot produces items to forecasted requirements instead of actual use. The benefit of the "exchangeables" program is that as end-items fail, they are required to be turned in within 48-hours. Therefore, the depot could ultimately work on a 48-hour, real-time forecast based on the end-items that are due-in-from-maintenance. However, the use of quarterly requirements, and EXPRESS daily repair determinations to meet these requirements, keeps this kind of customer responsiveness from occurring. In addition to increased visibility of ATS testing results, the depot could arrange a JIT delivery of failed SRUs to complete end-item repair in minimal time, and return a serviceable end-item to the CSI, greatly reducing AWP work-in-process inventories.

6-4-2 Information Quality Impacting Repair Capability:

One aspect of information quality is the development of bill of materials (BOM) by the SSC item managers. A responsive sustainment system relies on an accurate BOM to stock parts that are or may fail on an end-item. While the research for this thesis was being conducted, the SSC was working with the material and item managers for the F-16 to develop more accurate BOMs. However, without an accurate BOM, the SSC is unable to pre-stock piece-parts that may be required for repair because they are simply unaware of the existence of every part. This is further hampered by the time required to contract a source of supply for these piece-parts, while in the meantime an end-item remains in AWP status awaiting the contracting process, including first article testing. In conjunction with having accurate BOMs, the tracking of piece-part usage rates is not accomplished except on a very small scale. Part usage is only used to update the work control documents used by the depot repair technicians; then the WCDs are stored and not used to determine an overall part usage rate. The recent development of the DRILS information

system is helping the depot repair shops capture this information, but it is uncertain whether the usage rates are being used in conjunction with quarterly negotiated quantities to help determine SRU repair requirements. Tying piece-part usage rates to the negotiated repair or daily demand quantities could provide the foundation for the JIT delivery of piece-parts into the SSC.

The final aspect of information quality involves the use of daily demand data to determine quarterly requirements. The material manager incorporates the daily demand rate into a forecasting model that uses ratios to account for the variability in demand. Unfortunately, "the forecast is always wrong", as is any forecasting tool used by any company, and thus creates the need for safety stock. The GAO reported that of the 155 items they reviewed, "57 had problems related to the forecasting of inventory requirements used in developing the supply budget." (GAO 99-77, p.30) Therefore, SMAG could not meet its customers' needs. The primary reason for this was that "inventory requirements were understated by 18%." (GAO 99-77, p.30) These inventory requirements were understated as a result of expansion of some overhaul programs, as well as the replacement of some inventory items that could no longer be repaired. (GAO 99-77, p.31) This is information that was unavailable as a result of the nearly two year lead time in the Air Force budgeting of inventory requirements. Also, it has been suggested in the RAND report, Variability in the Demands for Aircraft Spare Parts, that the Variable-To-Mean-Ratio that material managers are employing is too high to correctly forecast demand. This report was outlined in more detail in Chapter 2.

6-5 Summary of Conclusions:

These are conclusions based on the findings of the value stream mapping of the avionics sustainment system accomplished in January 2003. Each conclusion is based on the lean principles of creating value through waste elimination and the flow of end-items through the system. They are meant to be preliminary in the sense that as the sustainment system begins its lean transformation, more waste will be identified and more root causes discovered that will need to be addressed. The following chapter presents recommendations based on these conclusions.

Chapter 7: Recommendations

The following recommendations for action in transforming the F-16 avionics sustainment system into a lean enterprise are based on the conclusions presented in Chapter 6. The intent of these recommendations is to instill a lean enterprise mentality into the Air Force sustainment system in hopes of better employing two-level maintenance, and allowing the Air Force to become in compliance with the congressionally-mandated 50/50 rule. These recommendations are not meant to be exhaustive, but simply intended to provide a starting point for the sustainment system to make a lean transformation.

The four overarching conclusions were:

(1) There is considerable waste in the system.

(2) The system has lost its customer focus.

(3) There is considerable negative impact from not having spare parts available for end-item repair.

(4) The lack of information quality and visibility is impeding the flow necessary to support a lean enterprise.

In order to address these conclusions, and support a lean transformation, the recommendations are designed to provide the greatest long-term benefit to the Air Force sustainment system. The overall recommendations focus on policy changes, new performance measures, reorganizations and team building, and greater information availability. These four overall recommendations are supported by the value stream map research presented in Chapter 3, and the identification of system constraints and waste presented in Chapters 4 and 5 respectively. The F-16 avionics sustainment system was only meant to be a process by which to map the flow of items through the Air Force sustainment system. Therefore, these recommendations would likely pertain to every sustainment system in the Air Force, and are intended to be expanded to other DoD services and agencies.

It is important to note that the lean transformation is meant to shorten the time that items are in the sustainment system, and is not grounds for reducing the workforce to achieve cost savings. Although the recommendations discuss reorganization, it is the movement of individuals to different organizations, and not the elimination of any positions. The idea is that as flow times

are reduced, the newly available capacity will be filled by pulling workload back into the organic repair facilities from contractor facilities. This will strengthen the core logistics capability outlined by Title 10 mandates. The workforce tied to the sustainment system is extremely professional, and can provide valuable information and continuous improvement insight for a sustained lean transformation. Also, the introduction of the Air Force's Agile Logistics program requires that some of these recommendations be adopted in order to allow the program to achieve its Air Force monetary and customer support goals.

7-1 Enhanced Flow and Customer Focus:

The goal of the following three recommendations is to provide for better flow of end-items through the sustainment system. This should be accomplished by modifying or better utilizing the 2LM policies already established in the sustainment system. By further exploiting policies establishing the Air Force's desire of moving from a three-tier to two-tier sustainment system, end-items should move through the system more quickly and efficiently achieving Air Force Logistics objectives. These recommendation buttress the main objective of Air Force Logistics, which is to "maximize operational capability by using high-velocity, time-definite processes to manage mission and maintenance uncertainty." (AFI 21-129, p.8) Again, these are not meant to be exhaustive, but these changes would prove the most important to beginning a sustained lean transformation, and supplement the Air Force's Agile Logistics program.

<u>*Recommendation One:*</u>

> *Eliminate the repair prioritization systems based on constraints and replace with a more simplified system using actual demand data obtained from supply systems, otherwise referred to as the "exchangeables" program and Due-In-From-Maintenance, to obtain greater customer focus.*

The Air Force employs EXPRESS, which as described in Chapter 4, is a repair prioritization system that considers carcass, funding, capacity and parts availability constraints in order to induct end-items into depot repair. The problem with this system is that while it focuses on problems based on priority, it hides emerging problems until they become the priority. For example, if all the attention is given to one or several end-items, while other end-items are also

failing but do not become a priority until backorders or MICAPs start developing. The Air Force then operates in a "fight-the-fires" mode where the fires never cease, since once one problem is solved, the next one becomes apparent. Therefore, the Air Force should work based on what "actual demand" is, and use the requirements and budgeting system as a guideline from which to determine how depot maintenance is functioning. This recommendation is meant to exploit the information seemingly being lost when the items are turned into the supply system.

Actual demand can be obtained by using the "exchangeables" program, which is established in AFI 21-129 as the need for operational units to turn failed end-items into depot repair within 48-hours of acquiring a serviceable unit or from the time the end-item is removed from the aircraft, whichever occurs first. This process, referred to as Due-In-From-Maintenance (DIFM), ensures that the depot always has a reparable inventory to pull end-items into the repair shops to refurbish and return to the serviceable inventory. However, while the bases are required to turn these items in within 48-hours, the items may not enter depot repair for sometime after that due to funding, parts or capacity constraints. Therefore, the sustainment system is sub-optimized, and does not meet actual warfighter demands.

Currently depot workload is dictated by a combination of sources. The first source is end-items driven into the repair shops by EXPRESS, which is an information system that controls daily depot repair actions, and the second is quarterly requirements, which are both batch-oriented processing and not repair-on-demand oriented processes. EXPRESS is similar to using the daily demand of end-items being obtained from the serviceable inventory, but it is constrained by the amount of funding, parts, and capacity the DMAG has to repair the end-items. Also, EXPRESS is driven by quarterly requirements loaded into the system by the SMAG material managers. Therefore, EXPRESS is simply a daily projection of SMAG quarterly determined requirements with the added constraints. This is an important cause of the unfortunate disconnect between depot maintenance and the rest of the sustainment system, since it implies that SMAG is the direct customer of depot repair rather than flying operations. Therefore, to provide a better customer focus, *EXPRESS should be simplified or eliminated as a daily workload tool*, and used only as a forecasting tool for SMAG to consider the constraints on the system. Conversely, the daily repair requirements should be determined using the "exchangeables" data that could be provided by the Standard Base Supply System (SBSS).

The yearly budgeting and forecasting process developed by the Depot Maintenance Business Area (DMBA) used by SMAG to determine what DMAG should repair is necessary in meeting the requirements of the DoD, but has no place in determining exactly what is repaired on a daily basis in depot shops. Therefore, using information available in SBSS from the "exchangeables" program should be used to determine daily repair requirements. As items fail, and are moved off-base into the supply system, SBSS is used to generate the required documentation to move the item to its proper repair facility within 48-hours in most cases. Therefore, SBSS should be used by each depot repair shop to determine what its repair requirements will be in the next several days. This effectively provides a 48-hour repair requirement forecast that will allow the shop to ensure it has the right parts, equipment, and capacity available.

This recommendation requires that end-item stock levels are at their proper levels to cover the sustainment system pipeline time, as well as work-in-process time. In cases where stock levels are below those desired, every effort should be made to fill available shop capacity (if underutilized) to meet these stock levels. Also, it is necessary to assume that all component parts are available to facilitate same-day repair of end-items, and that each day repair starts on new end-items. Component part availability is addressed in the next recommendation.

Recommendation Two:

> *Adjust inventory policies to better facilitate depot maintenance to provide a more reliable flow of end-items and piece-parts through the sustainment system to reduce in-process inventories. There are three stocking policies that were brought to light in this research. The first is that reparable end-items are retained in a central warehouse until inducted into the depot repair facility by the workload manager. The second is the lack of piece-parts available to meet the established repair requirements adding to AWP inventories and cannibalization actions. The last one is the prioritization differences between regional (e.g., Kadena AB, Japan) and depot (e.g., Ogden ALC) repair facilities for piece-part acquisition.*

Eliminate Centralized Reparable Inventories:

In support of this recommendation, reparable inventories should be moved from a centralized storage location directly to the responsible SSC reparable inventory. By co-locating the items needing repair with their associated repair shop, a great deal of "waiting waste", identified in the VSM, is removed. There was an average of 180 of 390 NVA minutes associated with moving end-items (in this case a MICAP) from a centralized warehouse to the depot repair shop when requested by the workload manager. However, this time is uncertain, and is much longer – one-to-two days - for lower-priority end-items in need of repair. Storing the reparable items close to the source-of-repair allows the workload manager and depot repairs shop to induct items as needed, with few or no AWM items in the shop. This can be accomplished with less uncertainty, and greater control over the flow of end-items arriving at depot repair. This along with the use of the daily demand data available from SBSS, outlined in Recommendation One, would allow the sustainment system to smoothly flow items through the depot repair process. Thereby, reparable end-items will only spend a minimal amount of time in the SSC reparable inventory area. Essentially as items arrive at the inventory location, they are almost immediately moved to the shop for repair. However, this increased flow of end-items is extremely reliant on an increase in piece-part stock levels.

Increased Piece-Part Availability:

While lean thinking in part focuses on eliminating inventory waste, in some cases inventory is required to support a customer focus. A good example and commercial benchmark of this is Boeing's avionics repair facility in Irving, TX. Boeing maintains a large piece-part inventory to ensure it can repair its customers' electronics items as quickly as possible. (Yoo, p.1) This requires the enterprise to determine or establish its goal(s). It is stated in AFI 21-129, that the overall mission of the Air Force sustainment system is to "provide aerospace systems ready to fly and fight, and to sustain mission-ready equipment at the time and place it is needed." (AFI 21-129, p.3) This suggests that a customer focus is a very important goal of the sustainment system, and not necessarily the meeting of budgets or financial goals associated with maintaining large piece-part inventories. These concepts are important in the financially constrained environment the Air Force operates in, but should not become the goal of the sustainment

system. This type of constraint should be used to drive continuous improvement in a manner that allows the sustainment system to accomplish the same tasks faster, smarter, and cheaper.

Striving for perfection through continuous improvement is then reliant on repairing end-items faster, smarter and cheaper. Faster and cheaper repair can be accomplished by maintaining larger piece-part inventories and smaller end-item inventories. The assumption is that if end-items are moving through the sustainment system faster, then not as many end-items will be required to cover increased pipeline times. It is evident in the VSM that increased pipeline times are caused by end-items being placed in an AWP status. The tradeoff needs to be made between increasing the amount of less-expensive piece-parts versus maintaining a larger than required inventory of the more expensive end-items. For example, the planned standard flow-time of the MLPRF in depot repair is five days. However, the actual average is 80 days (from ITS data) due to items entering AWP status. If the actual repair time were five days and transportation on either end of depot repair were two days each way, the total pipeline time would be nine days. The daily demand level was about three MLPRFs as of January 2003, and a quick calculation would indicate the need of a minimum of 27 end-items in the serviceable inventory. This does not account for the amount of inventory in mission-readiness spares kits, but is far less than the 262 MLPRFs in AWP status in January 2003. The number of AWP items, with a daily demand rate of three, provides an 87-day stockpile of end-items that are useless without the required piece-parts.

As the system becomes more responsive to customer demands, it may be possible to reduce these piece-part inventories. However, as it is evident from the large in-process inventories in AWP status, a larger investment of piece-parts is required in the F-16 avionics sustainment system. A tradeoff needs to be made to stock more piece-parts in an effort to reduce depot repair pipeline times, which would allow for reductions in the more costly and more space-consuming end-item inventory. Also, this would eliminate the need for flying units to use Readiness Spares Kits (RSPs) as a source of supply in times of end-item shortages, since items would flow with regularity from the depot and CSI. The increase in piece-parts would be further facilitated by the introduction of direct shipment of SRUs to depot repair from shops located at the same depot location.

Currently, serviceable SRUs are moved from the SRU shop to the depot centralized warehouse, where they are packaged, shelved, and then shipped back to the requesting SSC to

facilitate end-item repair. This is accomplished for two reasons. The first reason is to ensure accountability for the repair of items, so the SRU shop can receive payment for the repairs they have completed. Second, SRUs are distributed to more than one location, such as the F-16 regional repair facility at Kadena AB, Japan and Ogden Air Logistics Center. The regional repair facility has priority over the depot for receipt of SRUs to repair end-items, so by moving them to a central warehouse, they can be distributed to the proper location. However, this is an extraneous effort, since the SSC that works with the SRU shops could facilitate the same functions completed by the central warehouse. In addition, the end-item repair shops' waiting time would be reduced by directly moving serviceable SRUs to the SSC that supports end-item repair. This would be particularly helpful in instances that an end-item is in AWP status for a particular SRU. The SSC and end-item repair shops would no longer be reliant on the on-base depot shipping contractor to deliver these parts at its earliest convenience. This would also facilitate a just-in-time delivery of SRUs from the SRU repair shops to the end-item repair shops, thereby requiring the SSC to carry less SRU inventory.

Equalized Depot Repair Facility Prioritization:

End-items can be completely tested and repaired at two levels; these are regional and depot levels. Prioritization policy sets forth the requirement that piece-parts must be delivered to regional repair facilities before depot facilities. This is done because regional repair facilities directly support a specific MAJCOM in what is considered a "high-threat theater of operation", such as the regional repair facility at Kadena Air Base, Japan. However, this prioritization scheme is causing more harm to the overall sustainment system as discussed in Chapter 6. Therefore, both regional and depot facilities should be afforded the same prioritization levels, and thus requirements (orders) for piece-parts (SRUs) should be filled on a first-come-first-served basis. This would further reduce any uncertainty of when the depot would receive piece-parts to support its workload, further enhancing the reliability of the sustainment system pipeline time.

Recommendation Three:

Improve utilization of the base-level testing of end-items for screening purposes to increase the reliability of end-item and information flow to depot repair.

There are two potential changes for base level testing, either of which could be put into motion to achieve an improved sustainment system. Currently the ATS's responsibility is to screen end-items that are listed as RTS to ensure they are failing and cannot be corrected with simple actions, as described in Chapter 3. These simple actions include "reseating" the various SRU circuit cards and/or cross-cannibalization of SRUs between two or more end-items to make a serviceable end-item. Therefore, the first recommendation is to expand the ATS's scope of responsibility to allow each ATS to conduct complete testing of end-items before turning them into depot repair. The other is to eliminate the ATS, and move all avionics end-item testing to depot repair, basically establishing all avionics end-items as NRTS. The tradeoff is in the cost of increasing or decreasing the ATS's responsibilities. If the ATS's responsibilities were to be increased, they would accomplish more in-depth testing of failed end-items before turning them into base supply. However, if their duties were decreased or eliminated, the depot would be the sole source of testing, and would then be responsible for finding items that may not have failures that can be duplicated on a test stand.

If the ATS's responsibilities were increased, they would conduct all the testing necessary to determine exactly how or why an end-item is failing. This would require each ATS to be provided with "mock-up" SRUs to determine exactly which SRUs were failing. The costs of providing each ATS with mock-ups for every end-item are uncertain, and may not be feasible. Therefore, the elimination of the ATS would be the preferred recommendation as it expels a duplication of effort that is providing little real benefit.

The ATS is designed to be a screening process of avionics end-items, as defined in AFI 21-101, to ensure those that are removed from the aircraft are indeed failing and to keep serviceable end-items out of the sustainment system. If they are not failing on the test stand, then they are determined to be CND items and returned to the local serviceable inventory. However, if an item fails one test, the ATS stops testing, because it does not have the capacity to continue testing without the mock-ups, and turns the item into the supply system as unserviceable. They document the failure on tags attached to the item, but this information is not forwarded to the depot repair activity. Therefore, a duplication of effort ensues with the depot running the same tests, and the purpose of the ATS is uncertain other than to screen for CND items. It would be more cost effective to move all testing to the depot level to facilitate the quicker turn-in of

purportedly failed end-items to depot repair to decease the time an end-item spends in the sustainment system. This is highlighted by the fact that of all the 47 MLPRFs tested by the 388th fighter wing ATS last year, only 4 avionics end-items (8%) were found to be CND. Likewise, of the 812 avionics items tested last year, they found 146 avionics end-items (18%) that were CND, with armament systems making up the bulk of these. Therefore, the screening process does not seem necessary, and can be scrapped for a faster sustainment system. A faster sustainment system would facilitate fewer required end-items, and be more responsive to meeting customer demand.

7-2 New Performance Measures:

New performance measures or metrics would provide the sustainment system with an increased customer focus, and facilitate the flow of items through the system. The "performance measures the Air Force uses for depot maintenance are not meant to drive behaviors, but to provide trend information so that leadership could develop repair strategies and drive desired behaviors based on these strategies." (AFMCI 21-129, p.69) However, if the right measures are not being observed, and the strategies are more concerned with local goals and not system-wide goals, then the sustainment system can become severely hampered. This is highlighted in other research conducted by LSI and published in a thesis titled, *Air Force Sustainment Performance Metrics: An Exploratory Evaluation.* (McGillivray, p1) This research found that there was little or no connection between the performance measures used at various leadership levels in the Air Force sustainment system. (McGillivray, p.6) It concluded that this may cause metrics to be optimized locally to the detriment of system-wide performance, and that metrics must be designed to build up to higher-level objectives. (McGillivray, p.6)

Recommendation Four:

Institute new performance measures that provide increased customer focus, and encourage system flow, pull and continuous improvement by using a "Metrics Pilot Project" to track system improvement caused by introducing new performance measures.

The objective of this proposed pilot project is to identify and validate more effective metrics for the "organic" avionics sustainment system in a controlled experimental setting. This calls for the execution of a rigorous experimental design, very much like for medical experiments, where the effects and benefits of the new metrics can be quantified by testing three main hypotheses detailed in the text provided in Appendix A; (a) currently used metrics foster *local optimization* rather than *system-wide optimization*; (b) they do not allow measure of progress towards the achievement of system-wide goals and objectives because they do not allow visibility into the impact of depot maintenance on the warfighter, in this case flying operations; and (c) they are driving the "wrong behavior," causing sub-optimal decisions governing maintenance and repair priorities and practices and, as a result, undermining the efficiency and effectiveness of the sustainment system, despite the fact that the Air Force sustainment system has a dedicated and highly skilled workforce supporting the warfighter.

The pilot project is proposed to be executed during a one-year period. At the conclusion of the project, the results will be evaluated and plans for further pilot projects will be developed and implemented, as appropriate, to motivate continuous system improvement. One option might be to evaluate the effects of an expanded treatment regime to include both new metrics and the introduction of key lean practices into depot repair operations and the supporting supplier base. Actual experiment design is discussed in great detail in Appendix A, and identifies the need for control and treatment groups and the various experiment design options to address these.

The pilot project should focus on MRO operations relating to a specific set of pre-selected end-items that will effectively serve as the *units of analysis* in the experiment. These end-items consist of two samples: five high MICAP end-items where the lack of serviceable items results in not-fully-mission-capable aircraft, and a sample of five "supportable" end-items that are normally provided to the operating bases in response to backorder requisitions. While supporting the MICAP items is taken to represent fulfilling *urgent* customer needs, meeting backorder requisitions is defined as fulfilling *normal* customer needs. "Customer" is defined as the combat units; for the purposes of this pilot project, "customer" encompasses the operating bases.

Focusing on these specific end-items, the pilot project will test a new set of proposed *outcome metrics* as well as *enabling metrics*, and conduct an evaluation of their impact on the efficiency and effectiveness of the depot sustainment system. *Outcome metrics* represent

measures of value the depot maintenance system, taken as a total enterprise, delivers to the customer. They are customer satisfaction metrics. They gauge how effectively the customer's urgent and normal needs are met, how well they are met (e.g., in terms of product quality, customer wait-time), and how cost-effectively they are met (e.g., average cost of repair). *Enabling metrics* gauge how well the sustainment system performs various processes, functions and practices – by making sure that the organization as a whole is doing the "right job" as well as doing the "job right" – to deliver the defined outcome metrics benefiting the customer.

The following set of new metrics is proposed for the pilot project:

Table 7.1: Proposed New Metrics (Bozdogan (2), p. 3-4)

New Metrics	Brief Description
OUTCOME METRICS	
Urgent customer requirements satisfaction rate (UCRSR)	Ratio of the total number of serviceable end-items (in MICAP status) provided during a given period *to* total number of high MICAP items requisitioned during that period.
Normal customer requirements satisfaction rate (NCRSR)	Ratio of the total number of serviceable end-items provided during a given period *to* the total number of backorders issued by bases.
Weighted customer requirements satisfaction rate (WCRSR)	Weighted average of UCRSR and NCRSR, where the weights are quantified on the basis of the previously negotiated quantities using the "Quasi-EXPRESS" experiment. At WR-ALC, the weights may be derived from EXPRESS-driven inductions of MICAP and backorder items.
Unit cost of maintenance	Actual incurred unit cost of maintenance, reflecting full costs of materials, labor and cost of utilization of capital equipment, using the prevailing direct labor, overhead, and general and administrative (G&A) rates. Actual labor hours include accumulated labor hours for repairing end-items across all shops, including SRU repair.
Product quality	Total number of serviceable end-items produced by depot maintenance during a given period that are found to be defective (end-items with Quality Deficiency Reports (QDRs) sent back to the depot and, upon re-testing, are found to be defective).
Customer wait time	Total elapsed time (hours) from issuance of a requisition until receipt of a serviceable end-item at base supply that is available to base maintenance upon request.
ENABLING METRICS	
End-item shopfloor flow time (variance)	The statistical variance in shopfloor flow time, measuring variability (a Six Sigma concept to reduce process variation to drive continuous improvement).

	Cost of maintenance and repair (variance)	The statistical variance in unit cost of maintenance and repair, based on actually incurred costs and using prevailing direct labor, overhead and G&A rates (intended to eliminate waste and drive down unit costs through standard work processes and other lean methods).
	Productivity	Total number of serviceable end-items produced by depot repair per unit of labor-hours (e.g., 1000 labor-hours); not adjusted for unscheduled work-stoppages due to equipment failure in order to motivate depot-repair to put greater emphasis on preventive maintenance, a lean concept.
	Responsiveness	The ratio of *required Takt time* to the *observed Takt time,* to gauge how well depot maintenance as a system is responding to the pace of real customer demand for serviceable end-items. Detailed explanation is given in the text. *Takt time* is a basic lean concept in designing manufacturing operations to evolve a "pull-based" production system.
	End-item repair parts combined fill rate	Combined fill rate for a specific set of pre-defined repair parts and materials, based on previous repair history of end-items showing most frequently failing parts. This is in contrast with currently used issue or stockage effectiveness metrics at the individual part level. The metric is intended to motivate supply organizations to collaborate more closely in supporting the "fixer" and to motivate a much closer working relationship between the repair, supply and financial organizations.
	Supplier delivery performance	The "order-to-delivery" time for repair parts and materials obtained from suppliers, including the Defense Logistics Agency (DLA), measured in terms of total elapsed time from order-to-delivery for 50%, 75% and 95%, respectively, for all repair parts and materials requisitioned.

These proposed metrics are grounded in previous research which reveals that the causal structure of metrics used by the Air Force is much more complex than the conventional top-down hierarchical view of metrics. This suggests the adoption of an adaptive control feedback mechanism approach to metrics, not a top-down command-and-control approach; this is contrary to the fundamental design premise of the military. The main aim of these new metrics is to help coordinate the actions of numerous organizational entities, teams and processes through the establishment and clear communication of common goals, help foster a new culture, and develop metrics that motivate and reward teams striving to optimize system-level goals.

The expected benefits of the pilot project include identifying significant improvements in the efficiency and effectiveness of the avionics sustainment system that can migrate to many other component repair environments within the Air Force "organic" sustainment system, as well as other DoD sustainment systems. One of the key benefits would be showing the impact of depot maintenance on the warfighter. Also, the pilot project is expected to provide a framework for evaluating tradeoffs, leading to better decision-making. In addition, the pilot project is expected to test and codify a rigorous approach for introducing new metrics into the Air Force's metrics structure and for continually improving existing metrics. Finally, the pilot project will provide the commercial providers of contract maintenance services a new process for improving their performance metrics in a way that is synchronized with expected improvements within the "organic" sustainment system, so that the entire Air Force sustainment system can be optimized to provide the best support to the warfighter at the least cost.

7-3 Re-organization:

Re-organization is not meant to reduce workforce size, but to move various specialties into other organizations in order to provide a greater benefit to the overall sustainment system. This recommendation includes the development of product teams to address issues, such as BOM development and parts usage rates, to further enhance the flow of items through the sustainment system. This reorganization could be as simple as "matrixing", assigning individuals from one organization to another organization, individuals from SMAG into DMAG shops for improved coordination.

<u>*Recommendation Five:*</u>

> *Integrate supplier network to provide for enhanced buyer-seller relationships between SMAG and DMAG and to provide enhanced focus on flying operations customers.*

Current policy separates the SMAG and DMAG as a buyer-seller relationship. However, with a lean enterprise transformation, it has been established that integrating the customer into the supplier organization can provide substantial improvements. Also, since SMAG also acts as

DMAG's main supplier of reparable items, such as SRUs, this relationship would have a two-fold benefit. The first benefit would be a closer working relationship that would aid the daily repair of end-items using the metrics outlined in the Metrics Pilot Project. Also, by co-locating the material manager (SMAG) with the SSC (DMAG), requirements forecasting can be improved for developing future budgets. Likewise, the SSC will be better able to work with the material manager in developing an accurate BOM and parts usage information.

Additionally, re-organization would facilitate developing product specific teams tied to the separation of the repair shops. The repair shops are separated by the types of items they repair because they require different test stands and procedures, as well as personnel trained in different systems. For example, Ogden ALC avionics repair shops include radio frequency (RF), displays and indicators (DI), and processor/pneumatics (PP), to name a few. By organizing teams by shop with a supporting material manager, workload manager, production materiel technician, retail item manager, and material planner. These teams would be responsible for supporting the repair of all end-items the shop, such as RF, is responsible for, by using data to determine the best stocking procedures for piece-parts, and by quickly correcting any parts shortages; caused by incorrect or outdated BOMs, non-performing contractors, and/or unresponsive supply systems, which may impede the flow of end-items through the shop.

7-4 Improved Information Availability:

The Air Force uses numerous electronic information systems, each providing a different view of the overall sustainment system. There are several systems that draw upon the data available in these systems to provide a fairly complete view of the status of the sustainment system that material managers utilize. However, these systems do not provide maintenance technicians any information regarding the repair history of each end-item and whether or not parts are available for the repair of an end-item. The maintenance workers in all sections of the sustainment system rely on the information provided them from the supply technicians using specialized systems, such as SBSS; however this information is usually limited to quantity in the system, and not the status of each item.

Recommendation Six:

The Air Force should initiate a single information system to provide individual item status and history to maintenance technicians, as well as aggregate data, such as part usage rates and mean time between failures in an "easy to use" format, such as an Intranet, accessible by material, item and workload managers involved in the sustainment system.

This could be accomplished by introducing a bar-coding system that would provide several benefits. The first is that by bar-coding individual reparable items, it is possible to locate each item at any point in the sustainment system. Also, instead of forms and tags being manually "tied" to the item, they can be electronically "tied", which will facilitate faster repair shop inductions and forms verification, as well as provide each repair station with information on what tests and repairs have already been accomplished. In addition, this will facilitate depot repairs 48-hour workload visibility as laid out in sub-section 7-1-1. The depot will know exactly which items, both reparable SRUs and LRUs, will be entering the reparable inventory, and can plan the workload accordingly to meet actual customer demands. Finally, by bar-coding each reparable item a snapshot of repair history will be provided, which will allow the depot repair technicians to take actions based not only on testing data, but previous end-items repairs. Also, they may be able to identify other problems in the item, such as bad wiring that may be causing the item to fail. This could also be expanded to the aircraft level, whereby bar-coding each aircraft tail-number would allow for determination of repetitive failures of LRUs on the same aircraft. Thereby, flight line maintenance technicians will be better able to troubleshoot aircraft systems by providing this type of information.

Failure histories, such as outlined above, could greatly ease the difficult task of developing BOMs that provide an accurate portrayal of piece-parts that will be required to complete item repairs, as well as their usage rates. For example, the beta system referred to as DRILS, which is discussed in Chapter 4, allows item managers and production materiel technicians located in the SSC to see piece-part usage rates. However, it does not currently calculate the percentage of end-items requiring each applicable part on the BOM. Therefore, enhancing this system to readily provide this information to these individuals would provide a precise picture of the amount of each piece-part required to support the workload. In addition, material managers

responsible for SRUs, would have an actual demand forecast for determining their budget requirements to support the SRU, and in-turn, the end-item workloads.

The MLPRF end-item, as extrapolated from DRILs data from July 2001 to June 2002, required that the LNA be replaced on over 40% of these end-items. Therefore, of the roughly 500 units repaired in the depot, about 200 required this SRU. This then establishes what the SRU workload should be to support MLPRF repair. To expand beyond the SRU level, it would be possible to determine how many "receiver protectors" (RP), a commonly failing item on the LNA, would need to be purchased as a consumable item from an outside supplier to support the workload. During the same time frame the RP was replaced just over 50% of the time, which would set the purchase level at about 100 units.

This type of information visibility could greatly enhance the budgeting and requirements forecasting conducted on a yearly basis. The "real-time" data provided would be valuable in ensuring customer demand is being met not only by the LRU depot repair shops, but also the SRU depot repair shops that provide a considerable number of piece-parts for the LRUs. This would reduce the waste involved with WIP inventories, and allow for the repair of items that are actually needed by the flying operations customer to reduce the amount of wasted effort and resources in the sustainment system.

7-5 Summary of Recommendations:

These recommendations are aimed at improving customer focus to achieve the goals of a lean transformation, and the Air Force's Agile Logistics program on the working level. In addition, by improving the sustainment system, and all the tasks associated with depot maintenance, the Air Force will be able to move more depot maintenance activities from contractors to organic repair. This would allow the Air Force to satisfy the provisions of the congressionally mandated 50/50 rule, and allow the Air Force to maintain a larger core logistics capability. By establishing a faster, smarter, and cheaper sustainment system, the Air Force will be poised to meet the increasing challenges of maintaining aging aircraft.

The key to several of these recommendations is using systems already in place in the sustainment system, but using them more effectively to the benefit of the sustainment system. The "exchangeables" program established under 2LM has already been successful in keeping flight line and base maintenance units from holding items, and cannibalizing them until the point

that they need to be condemned by depot maintenance. The movement of items to the reparable inventory to be available for depot repair is a sound practice. Therefore, by using the visibility that the exchangeables program provides to more accurately forecast depot repair's workload 48-hours in advance, the sustainment system will be able to produce the flying operations' actual demands.

Along with exploiting this information, it would be necessary to change or modify the system's performance measures to reflect an increased customer focus. This would be accomplished by the introduction of new performance measures that are typically associated with lean enterprises. The effectiveness of these new performance measures would be determined using a pilot project that allows for the observation of their effects in a controlled experimental setting. This pilot project and new performance measures are introduced in the "Metrics Pilot Project" implementation plan provided in Appendix A.

In addition to the new performance measures, a re-organization of the depot workforce to better support the sustainment system would enhance customer focus. By adopting a customer focus on flying operations, SMAG and DMAG can integrate to supply the right part, at the right place, at the right time in the right quantity. This reorganization is meant to enhance the DMAG and SMAG working relationship by integrating the customer and supplier to benefit of flying operations and mission capability. Additionally, it would further support the forecasting and budgeting process that is necessary in acquiring the required funding to support depot maintenance.

Finally, enhancing the availability and quality of information that depot maintenance works with will aid in smoothing the flow of items through the system. Information will be easier to gather by introducing a bar-coding system to better track reparable items through the sustainment system. Improving repair traceability will provide the additional benefit of enhanced part usage and failure rates. This will allow the repair shop to accurately forecast piece-part inventory requirements.

These recommendations are not meant to be exhaustive, and are only the beginning of the continuous improvement process motivated by a lean transformation. They are, however, meant to provide a starting point for reducing the sustainment system pipeline time by improving the flow of items through the system, and providing an increased customer, flying operations, focus. In-turn, it will allow the Air Force to make more organic capacity available for acquiring an even

greater core logistics capability as spelled out in the, Title 10 mandated, 50/50 rule. The costs and benefits of the Air Force acquiring a larger core logistics capability are discussed in Chapter 8, as well as recommendations for future research in Air Force sustainment systems.

Chapter 8: Policy Analysis and Recommendations for Future Research

The bulk of this research addressed the need for depot maintenance to adopt lean enterprise principles. The efficiencies associated with lean principles will provide the Air Force the ability to free-up organic depot maintenance capacity. This will give the Air Force the option to move contracted workload back into organic facilities in order to comply with the provisions of the Congressionally-mandated "50/50 rule". This chapter examines the stakeholder positions of this workload allocation policy. In addition it addresses the impact that previous Air Force lean transformation efforts had on readiness because they lacked a systemic approach.

An example of this failure was the implementation of the Air Force Agile Logistics Program. This program often referred to as "lean logistics" began to decrease spare-part inventory levels based on overly optimistic supply system responsiveness goals. (GAO 99-77, p.33) Therefore, by employing an enterprise approach to a lean transformation the Air Force can build a more efficient and responsive sustainment system for the warfighter customer. This is necessary for the sustainment system to meet its customers' needs in order to improve the readiness of the Air Force, other military services and defense agencies.

8-1 Overview of the "50/50 Rule":

This congressional mandate is established in Title 10, Subtitle A, Part IV, Chapter 146, Section 2460-2469 of the United States Code. Section 2466 of the code establishes the "limitations on the performance of depot-level maintenance of materiel." (10 U.S.C. 2466) The statute sets the percentage limitation in the following text: (10 U.S.C. 2466(a))

> *Not more than 50 percent of the funds made available in a fiscal year to a military department or a Defense Agency for depot-level maintenance and repair workload may be used to contract for the performance by non-Federal Government personnel of such workload for the military department of the Defense Agency. Any such funds that are not used for such a contract shall be used for the performance of depot-level maintenance and repair workload by employees of the Department of Defense.*

The percentage limitations have fluctuated between 40% and 50% for "contract-repair" during the 1990s. There were several amendments to the original law governing depot-level maintenance workload. The first, in 1992, established the percentage of workload to be

accomplished by DoD personnel to be 60 percent. However, in 1997, the law changed the workload allocation form 60% to 50%.

The purpose of the workload allocation boundaries, as established by the Congress, is to ensure the DoD services and agencies maintain a "core logistics capability." The 1990's saw the DoD contracting more and more logistics capabilities to the private sector in an effort to fill the gap left by diminishing defense resources, including personnel. The intent of privatizing services was to drive down the cost of repair by competing available workload between the private and public sectors. In some instances, the Air Force uses the private sector to maintain systems that have close commercial counterparts or to repair items that the Air Force lacks the capability to repair. It also uses the private sector to fill capacity gaps when the Air Force sustainment system capacity cannot meet warfighter demand. Contractors from the private sector are used for maintenance, repair and overhaul (MRO) operations, as well as for designing, installing and maintaining modifications to aircraft and/or systems. The Air Force uses interim contractor support (ICS) and contractor logistics support (CLS) contracts to fill personnel gaps at DoD-owned depot repair facilities. Therefore, contractor-completed repair at contractor facilities, and contractor-completed repairs and support at public facilities are included in the contracted-dollars computation in determining a service's or agency's adherence to the 50 percent provision.

The General Accounting Office, in several reports on depot maintenance workload allocation, identified inconsistencies in the reporting of funding allocations between the public and private sectors. These problems were first reported in a 1998 report, *Defense Depot Maintenance: Information on Public and Private Workload Allocations*. Since this report was issued there have been considerable changes in the public-private workload allocation reporting procedures. (GAO 98-41, p.3) The changes, established by the 1998 Defense Authorization Act, were that the allocation would become 50% public (organic) and 50% private (contract) from the previous 60% and 40% allocation, respectively. Also, the act mandated annual reports from each service and defense agency of public-private allocations. Another addition was a definition of *depot-level maintenance*. This definition, stated in section 2460, is: (GAO 03-16, p.5)

> *Material maintenance or repair requiring the overhaul, upgrade, or rebuilding of parts, assemblies, or subassemblies and the testing and reclamation of equipment, regardless of the source of funds or the location at which maintenance or repair is performed. Depot maintenance also encompasses software maintenance,*

interim contractor support, and contractor logistics support to the extent that work performed in these categories is depot maintenance. The statute excludes from depot maintenance the nuclear refueling of an aircraft carrier, the procurement of major modifications or upgrades of weapon systems, and the procurement of parts for safety modifications, although the term does include the installation of parts for safety modifications.

In addition, the Office of the Secretary of Defense (OSD) has issued guidance to the various military departments in an attempt to further clarify reporting procedures. (GAO 03-16, p.5) In-turn, "the military departments have also issued internal instructions to manage the data collection and reporting process, tailored to their individual organizations and operating environments." (GAO 03-16, p.5) These changes were addressed in several subsequent GAO reports on workload allocation, highlighting the difficulties each service was having in reporting correct numbers, and inconsistencies in the workloads included in the reporting.

The series of GAO reports on depot-level maintenance workload allocation highlight improvements in the reporting process, but more importantly they examine each major service's – Navy, Army and Air Force – workload allocation numbers. It is evident that the Air Force has become more reliant on contractor support in an attempt to upgrade and modify aging aircraft fleets, and address diminishing source of supply issues with contractor assistance. The public-private funding levels are consolidated from several GAO reports and presented in Table 8.1.

Table 8.1: Air Force Public-Private Workload Allocation[7]

Air Force	FY96	FY97	FY98	FY99	FY00	FY01
Public $ (millions)	2,828	2,678	3,329	3,593	3,000	3,289
Private $ (millions)	1,128	1,122	2,408	3,012	3,181	3,551
Total Obligated $ (millions)	3,956	3,800	5,737	6,605	6,181	6,840
Public/Private %	71/29	70/30	58/42	54/46	48.5/51.5	48.1/51.9

In addition to previous year's allocation reporting, each service is required by the statutes to project future workload allocation for the next five years. These forecasts are presented in Table 8.2. They show that the Air Force intends to either reduce contractor funding or use a larger percentage of its increasing depot-maintenance budget towards organic workloads rather than to

[7] The table was generated using data from the following GAO reports: GAO/NSIAD-98-41 (1996-1997); GAO/NSIAD-99-154 (1998); GAO/NSIAD-02-95 (1999-2000); and GAO/NSIAD-03-16 (2001-2002) as noted in the Bibliography. All data was obtained from OSD by the GAO.

expand its contract workloads. However, in Section 342 of the 2002 National Defense Authorization Act, 10 U.S.C. 2466 was amended to exclude certain public-private partnerships from the 50% limitation, thus changing the reporting procedures once again. (GAO 03-16, p.6) This exclusion applies to funds expended for depot-level maintenance that is accomplished by nonfederal government personnel located at the various depot maintenance centers, but only applies until fiscal year 2005. (GAO 03-16, p.6) It is required that these exclusions are reported in the annual report submitted by each service and defense agency.

Table 8.2: Air Force Future Public-Private Workload Allocation[8]

Air Force	FY02	FY03	FY04	FY05	FY06
Public $ (millions)	4,117	4,261	4,386	4,485	4,557
Private $ (millions)	3,599	3,686	3,734	3,774	3,835
Total Obligated $ (millions)	7,716	7,947	8,120	8,259	8,392
Public/Private %	53.3/46.6	53.5/46.3	53.9/45.9	54.2/45.6	53.7/46.3
Private Exempted $ (millions)	14	16	16	16	N/A
Private Exempted %	0.2	0.2	0.2	0.2	N/A

8-2 Stakeholder Positions:

The benefits of the public-private workload allocation statutes need to be examined from the viewpoint of the three stakeholders – the Congress, the military services (Air Force), and the private contractors that would normally undertake depot maintenance workload.

8-2-1 U.S. Congress:

The Congress initially enacted the workload allocation limitations in the early 1990s when the services started to contract out more and more workload to private companies. Senator Inhofe of Oklahoma, in debates concerning changing the limitation from 60-40 to 50-50, stated that: "we are trying to keep some type of a ratio in place that would allow the public sector to be able to know that in case of war we are not going to be held hostage by one supplier." (Inhofe, p. S5909) Senator Inhofe also revealed in his testimony that the "whole reason that we (Sub-

[8] These data was reported in GAO/NSIAD-03-16 as noted in the Bibliography.

committee on Readiness) came up initially on this 60-40, which was a ratio – it was arbitrary . . .". (Inhofe, p. S5908)

Therefore, the Congress admits that the ratio is having some "National Security ramifications", but feels it is necessary until the military services define their own core logistics capabilities. Congress established its definition in statutory language in 1997 with the 1998 Defense Authorizations Act. By defining "Core Logistics Capability" within the public domain, Congress wanted to ensure the military services and defense agencies would retain the technical competence and resources necessary to respond to times of national defense contingency situations, and other emergency requirements. [10 U.S.C. 2464(a)(1)] Also, maintaining this capability is of considerable benefit to the warfighter even during "peacetime" or "normal" operating environments.

In addition to the military services contracting depot-maintenance workload to private companies, there was considerable excess capacity within the public depots. This became evident in the 1995 Base Realignment and Closure (BRAC) decision, which closed two (of five) Air Force Air Logistics Centers. Congress was concerned that depot-maintenance workload was being contracted out, creating even more excess capacity in the public facilities. In addition, with the excess capacity and no workload, they were concerned with the loss of federal-employee skills that are important in depot-maintenance surge capabilities. It was stated by Senator Hutchison of Texas that the issue is about the public sector maintaining a core capability to defend America. (Hutchison, p. S 5911)

8-2-2 Public-Sector (DoD and Air Force):

The DoD opposes the percentage limitation, whether 60-40 or 50-50, as mandated in 10 U.S.C. 2466. In testimony to the Defense Appropriations Committee, on March 6, 1996, Admiral Owens, then Vice Chairman of the Joint Chiefs of Staff, stated that in the Defense Department costs were 65 percent fixed and 35 percent variable. According to Admiral Owens, what they were trying to do was reduce those fixed costs, and in order to reduce fixed costs, they had to have greater privatization. This information was read by Senator Hutchison of Texas as presented in the 143rd Volume of the Congressional Record. Some other information presented by Senator Hutchinson was from testimony by Dr. John White, then Deputy Secretary of Defense – "Privatization provides substantial savings." Dr. White was looking for the flexibility

to allow the DoD to determine when workload should or should not be privatized. (Hutchison, p. S5910) These savings are realized by opening the workloads for competition to receive the best result at the best price. In addition, General Shalikashvili, then the Chairman of the Joint Chiefs, asked for the law to be changed. The law he was referring to was the 60-40 or 50-50 percentage limitation, so that "they (DoD) can have the full ability to decide what is core workload, what can be done in the private sector and how they can save money." (Hutchison, p. 5910)

The DoD feels constrained by the "50/50 Rule" and opposes it. It does not intend to contract out all workload, but feel they must have the flexibility to take advantage of the benefits associated with competing workloads or capturing technology advancements from the private sector. The DoD does favor the definition of "Core Logistics Capability", but wants the ability to determine exactly what that capability is for each service and agency.

Maintaining a core logistics capability in the Air Force allows the Air Force to quickly and directly meet its own needs. If the Air Force were dependent on the private sector, its needs may not be addressed as quickly or directly because of other contending workloads. Ultimately the private sector is concerned with the bottom line, and may place a more lucrative order ahead of the Air Force's order. Finally, the Air Force's maintaining a core logistics capability allows it to maintain the flexibility to meet continuously changing requirements due to the uncertainty of war and related contingencies. If the Air Force were bound by contracts, it could take a prolonged period of time to change existing contracts or enter into new contracts to meet these new needs. A revision in the contracting regulations may change this, but the competition requirements established by public contracting law require a considerable amount of lead time from requirements identification to receipt of product. Flexibility is an important aspect of the Air Force's Agile Logistics program, and accommodates continuously changing warfighter requirements.

Another benefit of maintaining a core logistics capability is that it encourages the military services to find a better way of doing business rather than relying on the private sector in many instances. As repair costs rise faster than repair budgets, the depot centers are forced to find faster, better and cheaper ways to repair items to support the warfighter. This forcing function has driven the Air Force to consider lean enterprise principles in order to meet warfighter needs with fewer resources, and enact change initiatives, such as the Agile Logistics program.

The mandates have some negative effects on the Air Force and other DoD services and agencies. The Air Force is especially constrained because it was in violation of the mandates in fiscal years 2000 and 2001. This constraint may have deprived the Air Force of the opportunity to take advantage of new technological advancements offered by the private sector that would have benefited the sustainment of certain weapon systems. The Air Force has not had the flexibility to move workload to the private sector to achieve greater efficiency. Similarly, if the Air Force lacks the capability to expand depot-maintenance capacity, and the Air Force is constrained from contracting with the private sector, the capacity shortfall then impacts readiness.

It is difficult to quantify the missed opportunities for achieving greater efficiency caused by the mandate because most of the workload allocation decisions are made at low levels (branch or section levels – see Figure 4.2 in Chapter 4) in response to direction by senior management. The senior management has directed that the Air Force should complete more tasks organically rather than relying on a contractor in order to bring it back in compliance with the mandate. Therefore, management is driving behaviors based on financial considerations, and not necessarily the best or most economical approach to depot maintenance

If the percentage limitation was removed, and the requirements that a core logistics capability be maintained and an annual report to track workload allocation were maintained, the statute may have better impact on the economic performance of depot-level maintenance. In this case, the services would be required to identify what they consider their core capability, with OSD approval, and they would be free to choose the most economical approach to maintaining that capability. The annual report would provide the administration and public a snapshot of where funding for depot-level maintenance is being spent. This would allow the services to determine what is best for supporting their very different customers by choosing their particular efficient solution. In this case, opportunities for greater efficiency would be realized and a more economical solution to depot-level maintenance obtained.

8-2-3 Private-Sector:

The private-sector viewpoint of the "50/50 rule" is expressed in a legislative package for 2003 written by the Industry Logistics Coalition (ILC). The private-sector feels that the current statutes limit the flexibility of the DoD to enter into progressive partnerships with the private-

sector to fully utilize and upgrade the capabilities of the public-sector depot facilities. (ILC, p.6) They feel that the limitation provision in 10 U.S.C. 2466 work against the public-sector achieving the most cost efficient and effective use of depot workloads. This is because the limitations also impact the introduction of commercial technology, business processes, and capability. (ILC, p.6) However, recent changes to the statutes have given the private and public-sectors more flexibility to develop these progressive partnerships.

"The fiscal year 2000 National Defense Authorization Act (NDAA) (section 341, P.L. 106-398) expanded the Military Service Secretaries' authority to designate public-sector depots as Centers for Industrial and Technical Excellence (CITEs)." (ILC, p.6) This designation allows these depots to lease excess infrastructure to private-sector firms. (ILC, p.6) This authority is established in 10 U.S.C. 2474. However, the attractiveness of this type of partnership relies on the private-sector firms' ability to acquire new business opportunities that would not have been available in their own facilities. (ILC, p.6) These partnerships were made more attractive by the fiscal year 2002 NDAA, which provided an exclusion of certain public-private partnerships from the workload allocation limitation. (ILC, p.7) This exclusion applied to depot-level maintenance and repair workload that was completed by non-Federal government personnel at a public CITE. (ILC, p.7) These types of partnerships were excluded from the percentage limitation in 10 U.S.C. 2466(a). However, this is only a pilot program that ends in the year 2006. The private-sector would like to see additional time added to the program or the elimination of any time limitation. (ILC, p.7) Many private sector firms feel that the any time limitation will have a negative impact on the private-sector's willingness to enter into or fully participate in these public-private partnerships. (ILC, p.7)

In addition to limited time horizons, the pilot program does not address the restrictions imposed by the 50% workload allocation limitation. (ILC, p.7) The private-sector believes that "the 50% limitation should be applied to where the work (i.e., public-sector depot) is performed rather than who performs the work (i.e., Government employees vs. private-sector employees, both based at public-sector depots)." (ILC, p.7) This would allow the DoD to have the flexibility to select the most effective support option while maximizing the work performed at a public-sector depot. (ILC, p.7)

The private-sector recommended the following statutory changes in the 2003 legislative package. First, the DoD should apply a consistent definition of core logistics capabilities to all

of the military departments and agencies. (ILC, p.8) This would eliminate the need for the workload allocation limitation provisions. (ILC, p.8) The next recommendation was to remove the requirement that all organic depot-maintenance be accomplished by Government employees, and limit the statute to apply only to Government-owned facilities no matter if public or private-sector employees are completing the work. (ILC, p.8) Another recommendation was that the percentage limitation should only be applied to where the work is accomplished rather than who performs the work. (ILC, p.8) The final recommendation was that the pilot program be extended without any time limitation in order to encourage entrance into these public-private partnerships by private-sector firms.

To buttress these recommendations, the private-sector has pointed out the benefits of maintaining dual sources of depot-maintenance and repair. Maintaining dual sources of repair and supply (two-separate locations) allows depot-maintenance to meet the customer repair requirements with no capacity shortfalls and improves responsiveness to the warfighter. (Browning, p.1) This philosophy relies on the availability of facilities, equipment, trained people and parts to support continuing peacetime requirements and surge periods. (Browning, p.1) In addition, dual sources of repair reduce the risk that some catastrophic event will interrupt warfighter support. (Browning, p.1) Also, warfighter support is enhanced by depot-maintenance's ability to rapidly respond to changing requirements and incorporate evolving technologies. (Browning, p.1) Some other benefits of duality are the "capability to respond to production (capacity) shortfalls", and "provide competitive pressures to preserve efficiencies and encourage innovation." (Browning, p.2) The close working relationships that would accompany duality also provide the organic depot a place to benchmark its performance against, and provide a source of improved processes and technologies. (Browning, p.3) The final argument to splitting depot-maintenance workloads between the public and private sector is that by providing the private-sector OEM workload, the OEM is able to remain competent in the support, maintenance requirements and processes of their equipment during the sustainment life-cycle. (Browning, p.3)

8-3 Lean Principles and Readiness:

In the 1990s the DoD and Air Force made a determination to reduce inventories and the logistics "footprint" of deploying forces. They accomplished this by adopting and initiating *lean*

logistics. However, the lean logistics employed by the Air Force seemed mainly concerned with reducing end-item and piece-part inventories and relying on a more responsive supply system to facilitate the flow of end-items through the sustainment system. A more responsive supply system has not emerged, and this type of *lean logistics* philosophy has impacted Air Force readiness and mission capability.

It was previously shown in the GAO report, *Air Force Supply: Management Actions Create Spare Parts Shortages and Operational Problems* (Chapter 2) that parts shortages have continued to have an adverse effect on readiness. This is mainly attributed to management issues in the SMAG; however, the SMAG is responsible for contracting depot-level maintenance to the private sector when it does not seem feasible to use organic sources. The "50/50 rule" could very likely hinder the SMAG's ability to contract workload capacity that is needed to meet customer demand. For example, the material manager is required to obtain ALC commander approval for new contract depot-repair requirements. This Workload Approval Package (WAP) process, as it is called, is required under the waiver the Air Force requested from Congress in order to help the Air Force come into compliance with the percentage limitation provision of 10 U.S.C. 2466.

Therefore, a material manager may allow some customer requirements not to be met because they are de-motivated by the need for this time-consuming and onerous package-generation and approval package. This process adds to the long-lead times required to establish a new contract between the DoD and commercial providers. The material manager must get approval to contract a workload before they can "advertise" the workload for competitive bidding by various commercial providers. This motivates the material manager to accept the reduced capacity of organic depot-level repair to meet some, but not all, of their requirements, and find some other solution to the capacity shortfall, such as organic depot-maintenance overtime to meet the repair requirements.

A dichotomy exists between the philosophy of *lean logistics*, relying more on contractor support and supplier integration, and the addition of the WAP to an already time-consuming contracting process. This impacts readiness, since the sustainment system is not able to operate in as responsive a manner as required by the reduced inventory philosophy. It also exacerbates the already prolonged contracting process. This shortfall between higher customer requirements and reduced organic depot capacity leads to the lack of serviceable end-items available to the

customer. In addition, it further exacerbates the prioritization of repair requirements based on funding, parts, carcass, and, most importantly, capacity constraints. In essence, the Air Force will never "catch-up" with its ever-increasing repair requirements, and may fall further behind, adding to the adverse impact on aircraft readiness that has already begun. By applying an enterprise approach to a lean transformation, the Air Force will improve efficiency, allowing depot-maintenance shops to eliminate the capacity shortfall created by the initial attempt at *lean logistics*. In addition, through continuous improvement, excess capacity will provide the Air Force the flexibility to compete depot-maintenance workload between the public and private sectors within the workload allocation limitations.

8-4 Recommendations for Future Research:

Each research project acts as a springboard to further research, in addition to providing insight into some topic of interest. This research has attempted to develop an improved understanding of the highly complex Air Force sustainment system through a case study of an F-16 avionics sustainment process. In the course of developing the recommendations for this research several other opportunities for additional research emerged.

The most effective future research would be the implementation of the Metrics Pilot Project that is recommended in Chapter 7 and presented in full-text in Appendix A. This pilot project would remove some of the existing metrics used to monitor depot-level performance (the metrics that are not consistent with lean principles), and in their place, establish new metrics that are geared towards customer satisfaction and lean principles. In addition to implementing these new metrics, the pilot project would be able to gauge the effects these new metrics have on customer satisfaction by using control and treatment organizations as comparison groups. The pilot project could also change the repair philosophy from a cost/funding driven batched processing to a customer oriented, and paced repair-on-demand process as highlighted by the Air Force's Agile Logistics program. These new metrics could help the sustainment system achieve a greater customer focus and more responsive supply and inventory policies and practices, and accommodate a re-organization that would support both of these goals. This pilot project could help diffuse best *lean* practices throughout the Air Force and/or DoD sustainment systems, and provide for increased readiness and mission capability.

A second recommendation for future research is a topic briefly discussed in the Chapter 7 recommendations. The research would involve a tradeoff analysis of the economic benefits achieved with increased piece-part inventories, and decreased end-item inventories. The idea here is that if more inexpensive piece-parts were available, and the sustainment system were to achieve continuous flow with no waste, then there would not be as large a requirement for the repair of the more expensive end-items. However, what must be considered is that the most effective location for these end-items is the serviceable inventory at each base versus piece-parts being stored at a central regional or depot repair facility. To expand this research one step further, an analysis of the Air Force's policy to designate aircraft for cannibalization as another inventory source would be of value. Examining the tradeoffs between maintaining extra aircraft to cover inventory shortfalls, and increased end-items or piece-parts would be useful. One challenge to this research would be that aircraft inventory levels are established by war-mobilization considerations that establish aircraft fleet sizes reflecting expected national defense contingencies and other emergencies.

In addition, it would be instructive to determine the value the Air Force or any service would place on "stocking-out" of a weapon system. In other words, what is the value or willingness-to-pay for one additional aircraft, if that aircraft is needed to complete any number of different missions? One would suspect that the Air Force would place greater value (more willing-to-pay) on an additional aircraft in a wartime contingency than peacetime training missions. By determining this willingness-to-pay, it may be possible to understand better the tradeoffs made between maintaining extra aircraft inventories versus increased end-item and piece-part inventories.

A final recommendation for future research would be to determine the feasibility of establishing an information system that would use the latest in bar-coding technology to provide enhanced real-time information to the Air Force sustainment system. Feasibility studies would involve the use of a single system to input aircraft, as well as end-item and piece-part repair data for real-time use and historical tracking. This information system could be used to support not only the repair of these items and systems, but also the supply and transportation aspect of the sustainment system. Likewise, a module of such a system would allow material managers to forecast future demand in order to aid the planning, programming and budgeting process.

There is any number of additional research studies that could use the information gathered and presented in this thesis. It is the hope of this thesis that the detailed study of the Air Force's sustainment system presented here will motivate further investigations of various other dimensions of the Air Force's complex sustainment system, leading to new insights and solutions.

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AFTERWORD

This research was completed in a desire to understand the Air Force sustainment system including all the interactions within the system. The need for this understanding was highlighted by an initial attempt to employ the herein proposed *Metrics Pilot Project*. Upon completion of the implementation plan for the project, several attempts were made to begin the experiment at the representative Air Logistics Centers. However, the enthusiasm that was originally expressed by these organizations seemed to wane and the experiment was put on hold. This may have been a miscommunication of expectations on the behalf of the researchers or the overwhelming number of new programs being initiated in the depot environment that took precedence over the experiment. While unfortunate, it gave us the opportunity to garner a better understanding of how end-items flow through the sustainment system including all the supporting organizational, financial, regulatory, and information technology structures.

Therefore, this thesis tried to capture how the system interacts within its regulatory framework, and with other systems (e.g., financial, organizational). In addition, the previous research conducted for the pilot project revealed that SMAG was concerned with the congressionally mandated 50/50 rule as impeding the system's ability to meet warfighter demands. However, it has become apparent that improving upon organic system inefficiencies could possibly provide the capacity required to meet warfighter needs.

These improvements to the system can be made under the premise of *Lean Thinking* by giving the Air Force sustainment system a more direct customer focus, and simplifying the process by making better use of information that is already available. Hence, the system will have a clear picture of customer demand and produce to that demand. This information could be shared with other organic depots or contractor facilities to ensure the sustainment system has adequate capacity to meet these demands. In order to aid in and determine the effectiveness of these system changes, including performance measure changes, it is encouraged that the *Metrics Pilot Project* be implemented. This could be accomplished though the assistance of an outside research organization, such as LSI at MIT, or conducted by the Air Force by using the implementation plan attached in Appendix A of this thesis.

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APPENDIX A:

Metrics Pilot Project for Military Avionics Sustainment: Experimental Design and Implementation Plan

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WORKING PAPER
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
ENGINEERING SYSTEMS DIVISION

METRICS PILOT PROJECT FOR MILITARY AVIONICS SUSTAINMENT: EXPERIMENTAL DESIGN AND IMPLEMENTATION PLAN

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EXECUTIVE SUMMARY

This working paper outlines the design of an experiment, employing a pilot project, for identifying and validating new metrics for managing the US Air Force military avionics sustainment system. The paper also presents a plan for implementing the pilot project. The experimental design allows for the quantification of the effects of the new metrics, while controlling for the effects of other factors impacting the observed outcomes.

Underlying the pilot project, and the proposed experimental design, are three main hypotheses derived from earlier research: (a) currently used metrics foster *local optimization* rather than *system-wide optimization*; (b) they do not allow measures of progress towards the achievement of system-wide goals and objectives, and, hence, do not allow visibility into the impact of depot maintenance on the warfighter; and (c) they are driving the "wrong behavior," causing sub-optimal decisions governing maintenance and repair priorities and practices and, as a result, undermining the efficiency and effectiveness of the sustainment system, despite the fact that the Air Force sustainment system has a dedicated and highly skilled workforce supporting the warfighter.

For the purposes of this pilot project, a *nonequivalent comparison group* experimental design is proposed. Such a design makes use of *before* and *after,* as well as *with* (treatment) and *without* (treatment) comparisons for two independent groups that are identical or highly similar to each other in terms of their essential characteristics. Here, one group is exposed to the *treatment,* while the other serves as the *control* group. *Treatment* refers to the introduction of new metrics, including "new operating rules"; *control* means an absence of new metrics. The Ogden Air Logistics Center (ALC) avionics sustainment site is proposed to serve as the *treatment* case and the Warner Robins ALC avionics sustainment site is proposed to serve as the *control* case. The two comparison groups are not equivalent in the sense that they differ in terms of the *new metrics* that would have a measurable impact on the outcomes.

In both cases, sustainment is defined broadly to encompass both the maintenance, repair and overhaul (MRO) operations and the attendant procurement, materiel, financial and supply chain management functions and organizations. A proposed back-up plan is to use a simpler *one-group-pretest-posttest* experimental design framework focusing only on the Ogden ALC avionics sustainment site. Under this back-up design *before* (i.e., a defined period prior to the introduction of new metrics) would represent the *control* case and *after* (i.e., a defined period following the introduction of new metrics) would represent the *treatment* case.

The pilot project is proposed to be executed during a one year period. At the conclusion of the project, the results will be evaluated and plans for further pilot projects will be developed and implemented, as appropriate. Further pilot projects may entail, for instance, an evaluation of the effects of an expanded treatment regime, including both new metrics and introduction of lean practices, into depot repair operations and the supporting supplier base.

The pilot project will focus on MRO operations relating to a specific set of pre-selected components (end-items or Line Replaceable Units – LRUs) that will effectively serve as the *units of analysis* in the experiment. These end-items consist of two samples: five high MICAP

(mission capability) end-items, where the lack of serviceable items results in not-fully-mission-capable aircraft, and a sample of five "supportable" end-items that are normally provided to the operating bases in response to backorder requisitions. While supporting the MICAP items is taken to represent fulfilling urgent customer needs, meeting the backorder requisitions is defined as fulfilling normal customer needs. "Customer" is defined as the combat units; for the purposes of this pilot project, "customer" encompasses the operating bases.

The following list of the MICAP and normally supportable end-items, to serve as the units of analysis at the Ogden ALC, are currently being considered:

Sample of MICAP End-Items

Shop; National Stock Number Designation	Description	Abbreviation
Radio Frequency Shop		
1270-01-233-0011WF	Modular Low-Power Radio Frequency	MLPRF
5985-01-212-2950WF	Antenna	ANTENNA
1270-01-102-2962WF	Low-Power Radio Frequency	LPRF
Display and Indicators Shop		
6625-01-193-8861WF	Multi-Function Display	MFD
Microwave Shop		
1270-01-238-3662WF	Dual Mode Transmitter	DMT
1270-01-132-6867WF	Low Noise Assembly*	LNA

NOTE: *Shop Replaceable Unit (SRU), which is an important part of MLPRF.

Sample of Supportable End-Items

Shop; National Stock Number Designation	Description	Abbreviation
Displays and Indicators Shop		
1270-01-468-8658WF	Heads-Up Display Electronic Unit	HUD EU
5826-01-052-1945NT	Mode Select Coupler	MSC
Computer and Inertial Shop		
6615-01-448-6152WF	Digital Flight Control Computer	DFLCC
6615-01-042-7834WF	Rate Gyro Assembly	RGA
Processor and Pneumatics Shop		
5998-01-080-3978WF	Jettison Remote Interface Unit	JRIU
1290-01-109-1499WF	Missile Release Interface Unit	MRIU

These end-items will be matched with the same or analogous end-items maintained and repaired at the Warner Robins ALC. In particular, the high MICAP items will be examined closely to make sure that those selected share technological commonality and are highly comparable in terms of the underlying causes of their MICAP status. An option being considered is to focus directly on supportable end-items reflecting a stable maintenance environment and defer, for now, an analysis of the MICAP items since they may often involve a "chaos" environment and may introduce an added layer of complexity into the pilot project.

Focusing on these specific end-items, the pilot project will test a new set of proposed *outcome metrics* as well as *enabling metrics*, and conduct an evaluation of their impact on the efficiency

and effectiveness of the depot sustainment system. *Outcome metrics* represent measures of value the depot maintenance system, taken as a total enterprise, delivers to the customer. They are customer satisfaction metrics. They gauge how effectively the customer's urgent and normal needs are met, how well they are met (e.g., in terms of product quality, customer wait-time), and how cost-effectively they are met (e.g., average cost of repair). *Enabling metrics* gauge how well the sustainment system performs various processes, functions and practices – by making sure that the organization as a whole is doing the "right job" as well as doing the "job right" – to deliver the defined outcome metrics benefiting the customer.

The following set of new metrics is proposed for the pilot project:

New Metrics	Brief Description
OUTCOME METRICS	
Urgent customer requirements satisfaction rate (UCRSR)	Ratio of the total number of serviceable end-items (in MICAP status) provided during a given period *to* total number of high MICAP items requisitioned during that period.
Normal customer requirements satisfaction rate (NCRSR)	Ratio of the total number of serviceable end-items provided during a given period *to* the total number of backorders issued by bases.
Weighted customer requirements satisfaction rate (WCRSR)	Weighted average of UCRSR and NCRSR, where the weights are quantified on the basis of the previously negotiated quantities using the "Quasi-EXPRESS" experiment. At WR-ALC, the weights may be derived from EXPRESS-driven inductions of MICAP and backorder items.
Unit cost of maintenance	Actual incurred unit cost of maintenance, reflecting full costs of materials, labor and cost of utilization of capital equipment, using the prevailing direct labor, overhead, and general and administrative (G&A) rates. Actual labor hours include accumulated labor hours for repairing end-items across all shops, including SRU repair.
Product quality	Total number of serviceable end-items produced by depot maintenance during a given period that are found to be defective (end-items with Quality Deficiency Reports (QDRs) sent back to the depot and, upon re-testing, are found to be defective).
Customer wait time	Total elapsed time (hours) from issuance of a requisition until receipt of a serviceable end-item at base supply that is available to base maintenance upon request.
ENABLING METRICS	
End-item shopfloor flow time (variance)	The statistical variance in shopfloor flow time, measuring variability (a Six Sigma concept to reduce process variation to drive continuous improvement).
Cost of maintenance and repair (variance)	The statistical variance in unit cost of maintenance and repair, based on actually incurred costs and using prevailing direct labor, overhead and G&A rates (intended to eliminate waste and drive down unit costs through standard work processes and other lean methods).

Productivity	Total number of serviceable end-items produced by depot repair per unit of labor-hours (e.g., 1000 labor-hours); not adjusted for unscheduled work-stoppages due to equipment failure in order to motivate depot-repair to put greater emphasis on preventive maintenance, a lean concept.
Responsiveness	The ratio of *required Takt time* to the *observed Takt time,* to gauge how well depot maintenance as a system is responding to the pace of real customer demand for serviceable end-items. Detailed explanation is given in the text. *Takt time* is a basic lean concept in designing manufacturing operations to evolve a "pull-based" production system.
End-item repair parts combined fill rate	Combined fill rate for a specific set of pre-defined repair parts and materials, based on previous repair history of end-items showing most frequently failing parts. This is in contrast with currently used issue or stockage effectiveness metrics at the individual part level. The metric is intended to motivate supply organizations to collaborate more closely in supporting the "fixer" and to motivate a much closer working relationship between the repair, supply and financial organizations.
Supplier delivery performance	The "order-to-delivery" time for repair parts and materials obtained from suppliers, including the Defense Logistics Agency (DLA), measured in terms of total elapsed time from order-to-delivery for 50%, 75% and 95%, respectively, for all repair parts and materials requisitioned.

These proposed metrics are grounded in previous research which reveals that the causal structure of metrics used by the Air Force is a lot more complex than the conventional top-down hierarchical view of metrics [See references given at the end of this paper]. This suggests the adoption of an adaptive control feedback mechanism approach to metrics, not a top-down command-and-control approach. The main aim of these new metrics is to help coordinate the actions of numerous organizational entities, teams and processes through the establishment and clear communication of common goals, help foster a new culture, and develop metrics that motivate and reward teams striving to optimize system-level goals.

The implementation of these new *outcome metrics* and *enabling metrics* includes the concurrent adoption of a number of *new operating rules*, to pave the way for the adoption of these new metrics by removing some obvious roadblocks. These new operating rules include both incentive systems and rewards. It is expected that improvements in these *outcome metrics* (customer satisfaction measures) will impact the warfighter directly: (a) by leading to a *reduction* in TNMCS (Total Not Mission Capable for Supply), through improvements in base-supply of serviceable items, that should directly help to increase the FMC (Fully-Mission-Capable) rates; and (b) by promoting greater efficiency in base-repair operations – through reduced cannibalization in light of greater availability of serviceable items, such that the available resources can be put to more productive pursuits – which would tend to reduce the TNMCM (Total Not Mission Capable for Maintenance) rates and thereby increase the FMC rates.

A basic tenet of this proposed plan is that the pilot project should be "owned" by the principal participating organizations that will be responsible for its execution based on agreed-upon ground rules and operating procedures. The role of the MIT LSI researchers will be to provide technical support and data analysis.

The execution of the pilot project will require the development and tracking of a detailed set of data, for the previous year as well as during the time the pilot project is being executed, in order to conduct the necessary analytical tasks required to test the validity and benefits of the new metrics. Weighed against the expected future benefits of the new metrics, the extra cost of such a data collection effort is an investment well-worth making -- representing a potentially large benefit-cost ratio.

The expected benefits of the pilot project include significant improvements in the efficiency and effectiveness of the avionics sustainment system that can be migrated to many other component repair environments within the Air Force "organic" sustainment system. One of the key benefits would be showing the impact of depot maintenance on the warfighter. Also, the pilot project is expected to provide a framework for evaluating tradeoffs, leading to better decision-making. In addition, the pilot project is expected to prototype and codify a rigorous approach for introducing new metrics into the Air Force's metrics structure and for continually improving existing metrics. Finally, the pilot project will provide the commercial providers of contract maintenance services a new process for improving their performance metrics in a way that is synchronized with expected improvements within the "organic" sustainment system, so that the entire Air Force sustainment system can be optimized to provide the best support to the warfighter at the least cost.

To ensure successful execution of the pilot project, the participating organizations are invited to review and approve the proposed experimental design and implementation plan on a fast-track basis, come to a common understanding of the new working relationships required to implement the project through concerted action, help develop the necessary data and put in place the needed data monitoring steps, and work with the MIT LSI research team on a collaborative basis to help launch and continue to actively support the pilot project.

I. INTRODUCTION

This working paper is designed to provide a proposed conceptual and operational plan for the implementation of the **Metrics Pilot Project on the Sustainment of Avionics Systems.** The pilot project was recommended by the Enterprise Integration Team (EIT) of the Lean Sustainment Initiative (LSI) at a meeting of the LSI Steering Group on 19 December 2001 and was approved by the Steering Group. The Steering Group consists of the senior leadership of the LSI stakeholders community encompassing both the Air Force sustainment system and commercial providers of contract maintenance and repair services supporting the Air Force. This proposed planning document is presented for review and approval by the participating stakeholder organizations.

The rest of the working paper is organized into the following parts:

- •Motivation
- •Objectives
- •Hypotheses
- •Experimental design
- •New metrics and related data requirements
- •Project structure
- •Resource requirements
- •Expected deliverables and benefits
- •Major tasks and project schedule; and,
- •Next steps.

A glossary of the acronyms used in the paper is given in Attachment A.

Throughout the paper, the terms "depot-repair" and "depot maintenance" may be used interchangeably. The intent here is to define the avionics sustainment system broadly to encompass both the MRO operations and the attendant procurement, materiel, financial and supply chain management functions and organizations. This is consistent with the broader view adopted in the paper that the depot maintenance system, however it may be currently structured organizationally, is, in effect, in the business of creating and delivering best value to the *real* customer, which is the combat units. For reasons detailed in the text, definition of the "customer" is extended to encompass the operating bases, where base supply effectively serves as the actual interface between the "customer" and the depot maintenance system.

II. MOTIVATION

A major motivation for performing this pilot project is to explore, identify, define and test metrics and analytical methods for linking improvements in performing avionics-related component maintenance and repair services to the achievement of system-wide performance improvements (e.g., increased rates of fully-mission capable (FMC) aircraft). This would enable tradeoff decisions *between* the achievement of system-level objectives (e.g., increasing the rates of FMC- aircraft) *and* actions designed to improve component-repair operations (e.g., at the depot level). Hence, there appears to be a real need not only for a disciplined process for identifying more effective metrics, and formal ways of validating their effectiveness, but also for an analytical link between *local* improvement actions and *system-level* performance outcomes.

Generally speaking, it is instructive to test out the feasibility, workability and usefulness of new business processes and practices in a controlled "pilot project" setting before their wholesale implementation throughout the Air Force sustainment enterprise. It would similarly be beneficial to test the adoption of new performance metrics in a controlled experimental setting. Thus, a well-designed pilot project concentrating on avionics MRO operations is expected to validate the usefulness and expected benefits of a new set of "intervention" metrics driving avionics-related sustainment operations. The results of such a pilot project are expected to have considerable

spillover benefits for other component-level repair operations as well in both government and industry.

III. OBJECTIVE

The objective of this pilot project is to evaluate the overall effectiveness, operational feasibility, workability and potential benefits of a new or modified set of metrics designed to foster system-wide optimization of the sustainment system to benefit the warfighter, concentrating on "organic" avionics MRO operations and the related procurement, materiel, finance and supply organizations, in a controlled experimental setting.

IV. HYPOTHESES

The main hypotheses motivating the pilot project, which can be tested by conducting the proposed experiment, are presented below. Following this discussion, interactions between the bases and depot-repair are explored and the implications of these interactions for experimental design are outlined. A more detail discussion of the underlying research leading to the main hypotheses outlined below can be found in references given at the end of this paper.

A. Main Hypotheses

Three main hypotheses driving the pilot project are stated and discussed below.

Hypothesis 1: Currently used metrics generally foster *local optimization* rather than *system-wide optimization.* Consequently, the performance of the sustainment system, in terms of its efficiency and effectiveness, is compromised and the sustainment system does not provide the best support to the warfighter. *If currently used metrics were realigned or largely replaced by new metrics that drive behavior towards improving the overall performance of the sustainment system rather than showing better financial or other performance measures locally, then the efficiency and effectiveness of the "organic" avionics sustainment system will improve, resulting in better support of the warfighter.*

Discussion: Current levels of performance of the "organic" avionics sustainment system are the outcome of many root causes reflecting a complex set of interactions among numerous factors, including currently used metrics, driving production priorities and practices. These factors include the quality of the capital stock (e.g., testing equipment), capability of the workforce, funding availability, policies governing investment in new spares, availability of repair parts and materials, contracting practices, organizational structure and the division of responsibility among various organizational units as well as the degree of cooperation among them, and a host of broader government policies, regulations and procedures governing many aspects of the sustainment system. The root causes underlying current performance levels require a wholesale attack to eliminate them. These root causes, or the factors contributing to them, may not disappear in the course of the pilot project. That is, introduction of new metrics cannot be expected to completely eradicate the negative effects of some or all of these factors. However, new metrics may well positively influence some of them to make a significant difference in

terms of inducing local behavior that is more conducive to system-wide optimization, resulting in enhanced system-wide performance outcomes.

Hypothesis 2: Currently used metrics generally do not allow measures of progress towards the achievement of system-wide goals and objectives; the metrics do not allow visibility into the impact of depot maintenance on the warfighter. For example, they do not allow for quantifying the *incremental impact*, on F-16 mission capability rates, of an increase in metrics gauging the availability of repair parts and materials for the maintenance of the F-16 avionics system through an *incremental investment* in more parts and materials. Consequently, informed tradeoff decisions cannot be made at the system level to provide more cost-effective support to the warfighter. *If existing metrics were realigned or largely replaced by a new set of metrics that are linked together at multiple levels in the form of a cascading, mutually-supporting, chain of metrics, then the incremental contribution of sustainment initiatives at various levels to overall system-wide performance outcomes can be more readily and transparently gauged, yielding informed tradeoff decisions to deliver better value to the warfighter.*

Discussion: The metrics currently used by the Air Force sustainment system generally do not allow measurement of progress towards the achievement of system-wide goals for several reasons. A major reason is that depot maintenance metrics are fundamentally in conflict with customer support metrics. Also, currently used metrics are not consistent *vertically* from the highest to the lowest echelons (i.e., from the "corporate" Department of Defense to the Air Staff to AFMC to the shop-floor). Further, they are not consistent *horizontally*, from the flight line to the shop-floor and beyond, encompassing the supplier network supporting depot-repair. The supplier network covers numerous suppliers providing new spares and repair parts, the Defense Logistics Agency (DLA), and commercial providers of contract maintenance, repair and overhaul (MRO) services supporting the depots. In addition, currently used metrics often reflect financial and other measures driving internal priorities of organizational silos. Moreover, they lack accountability and can often be "gamed" by managers at virtually all levels. Finally, there is considerable confusion between metrics, performance measures, process indicators and status reports.

These shortcomings of the currently used metrics can be overcome by realigning or largely replacing existing metrics with a new set of metrics that are linked together and are mutually-supportive, both and *vertically* (e.g., from the Air Staff to AFMC to the shop-floor) and *horizontally* (e.g., from the flight line to the shop-floor to the supplier network. The "House of Metrics" approach mentioned in a companion LSI Working Paper[9] and outlined in an MIT Master's Thesis performing an exploratory evaluation of the current metrics used by the Air Force sustainment system[10], can be helpful in constructing such a metrics structure, informed by the quantitative empirical results of the "Metrics Thermostat" research at MIT focusing on the F-16 sustainment system[11]. Substantively, these results can be aided by the introduction of lean

[9] Kirkor Bozdogan, "Summary of Findings, Current Projects and Planned Activities," Working Paper, Enterprise Integration Team of the Lean Sustainment Initiative, Massachusetts Institute of Technology, 30 August 2002.
[2] Stuart McGillivray, "Air Force Sustainment Performance Metrics: An Exploratory Evaluation," Master's Thesis, Engineering in Logistics, Massachusetts Institute of Technology, June 2002.
[11] See John R. Hauser, "Metrics Thermostat," *The Journal of Product Innovation Management*, Vol. 18, No. 3 (May 2001), 134-153. For a description of LSI research applying the "Metrics Thermostat" approach to the Air Force sustainment system, see Bozdogan, *op cit.* and refer to Keith A. Russell (Lt. Comdr., USCG), "Reengineering

performance metrics derived from lean principles for managing complex modern enterprises, tailored to the sustainment system. Lean thinking is defined as the "dynamic, knowledge-driven and customer-focused process by which all people in a defined enterprise continuously eliminate waste with the goal of creating value."[12]

Hypothesis 3: Currently used metrics by the Air Force sustainment system are driving the "wrong" behavior, causing sub-optimal decisions governing maintenance and repair priorities and practices and, as a result, undermining the efficiency and effectiveness of the sustainment system.
If existing metrics were realigned or largely replaced by a new set of metrics that provide greater incentives for both "doing the right job" and "doing the job right", the efficiency and effectiveness of the sustainment system would improve, resulting in better support for the warfighter.

Discussion: Examples of "wrong" behavior that could be induced by the currently used metrics include improving the sales performance of a shop by placing higher priority on the maintenance of certain assets to offset losses in other areas, inducting into repair those end-items that are easier to fix and that bring quick sales benefits, or "gaming" the system in various ways (e.g., budgeting for high overtime, negotiating for higher standard rates). Other forms of "wrong" behavior that might be caused, at least in part, by currently used metrics may include cannibalization[13], lack of availability of repair parts and materials, extensive downtime for testing equipment for lack of the required repair parts, insufficient cross-training of the workforce, excessive delays in contracting, and lack of coordination among the various organizational entities responsible for depot maintenance and supply functions. It is difficult to know, *a priori*, how new metrics might realign existing incentives such that various classes of "wrong" behavior can be reduced or eliminated. However, it is possible to introduce certain "gatekeeper" metrics forcing greater cooperation, for example among various organizational entities responsible for the supply of both wholesale and retail items necessary for depot repair. Similarly, well-defined outcome metrics could induce greater cooperation between depot repair and supply operations.

It must be emphatically stated that the Air Force sustainment system has a dedicated and highly skilled workforce supporting the warfighter. Any references in this document to possible "wrong" behavior that might be induced by currently used metrics pertains only to possible

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Metrics Systems for Aircraft Sustainment Teams: A Metrics Thermostat for Use in Strategic Priority Management," MS Thesis, Aeronautics and Astronautics *and* Technology and Policy, Massachusetts Institute of Technology, December 2000.

[12]See Earll Murman, et al., *Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative* (Great Britain [Houndmills, Basingstoke, Hampshire RG1 6XS] and New York: Palgrave, 2002), p. 90.

[13] Cannibalization refers to the removal of a serviceable component from one end-item which is already awaiting parts (AWP-G) for use in making another end-item being repaired serviceable. Usually a distinction is made between robbacks and cannibalization. Robbacks refer to cases of removing a serviceable component from an end-item in AWP status, where the component is not physically attached to that end-item, for use in making another end-item in the repair process serviceable. In the case of cannibalization, the serviceable component that is removed from an end-item in AWP status is physically attached to that end-item. This may be a distinction without a difference. See Air Force Materiel Command (AFMC), Hill Air Force Base, Industrial and Logistics Training Division, *AWP Process Overview Training Program, Student Handout*, Command Course MOODMM000300SU, Revision January 2001, p. 5-1.

organizational behavior that might be shaped by at least some of these metrics; such references in no way reflect a negative comment on the capability and commitment of the sustainment workforce, individually or taken as whole.

B. Base-Depot Interactions

The main hypotheses presented above involve certain base-depot interactions that need to be considered in the experimental design for the pilot project. To give a simple example, base repair may engage in extensive cannibalization to make up for lack of serviceable end-items or availability of repair parts and materials, perhaps because depot maintenance may have placed the wrong priority on what items to repair. Alternatively, to conserve base budgets, the bases may engage in extensive cannibalization on items before they are sent to the depot for repair, causing the depot to undertake much more expensive repair on those end-items in part because they may have suffered collateral damage in the course of cannibalization actions. Further, depot-repair may be forced to tie-up a considerable number of labor hours and testing-equipment time to the testing of end-items forwarded from bases because they were identified as "Cannot Duplicate" (CND) at the bases and that are later classified by depot repair as "No Fault Found" (NFF). Still another example may include cases where, competing for repair parts and materials, bases often trump depot-repair, thus depriving depot-repair of needed parts and materials and adversely affecting depot repair. These examples can be extended to include others.

The main issue here is how best to control for these strong two-way interactions between the bases and depot-repair, essentially to make sure that the base-to-depot influences (i.e., negative or positive effects flowing from the bases to depot-repair) do not end up confounding the effects of the new metrics applied to depot-maintenance. The attention here, then, is focused on how best to take into account the key base-to-depot influences; the proposed experimental design outlined below takes precautions regarding such base-to-depot influences.

Meanwhile, it is argued that the depot-to-base influences – that are expected to be mostly positive under the pilot project -- can be safely ignored. The reasoning for this assumption can be laid out as follows. It can be argued that any improvements in depot-maintenance efficiency and effectiveness due to the new metrics will result in improvements in base supply availability. This, in turn, will help reduce the numerical value of the Total Not Mission Capable Supply (TNMCS) metric. As a result, cannibalization at base-repair will most likely be reduced. Consequently, workforce and testing equipment resources will be freed-up for more productive uses. Ultimately, this will most likely lead to a reduction in the numerical value of the Total Not Mission Capable Maintenance" metric. Ultimately, such a positively-reinforcing chain of developments at the base-level – all due to improvements in depot-maintenance performance – can be expected to result in higher TMC rates for the warfighter.

All else remaining equal, because of these expected positive effects flowing from depot-maintenance to base-level supply and repair operations, over time any negative feedback effects flowing from depot-maintenance to the bases will be reduced in importance. Thus, for the purposes of this pilot project, it should prove sufficient to control for possible base-to-depot influences (negative or positive), while ignoring any possible depot-to-base negative influences

(this assumes that the effects of new metrics will be positive),[14] keeping in mind that that is argued that assumed that the boundaries of the pilot project can be defined as depot repair plus the supporting supply organizations and networks. Bases are thus taken as the "customer" and outcome metrics are defined as measures of customer satisfaction, as noted below in more detail.

V. EXPERIMENTAL DESIGN

This section of the paper outlines the experimental design options, defines the two comparison groups being considered for the pilot project (i.e., the Ogden ALC and Warner Robins ALC avionics sustainment systems), describes the units of analysis, and specifies the planned time period for the pilot project. A discussion of the new metrics, as well as other factors of interest in designing and executing the pilot project, is presented in the next section.

A. Experimental Design Options

There are a number of experimental design options that can be considered for the pilot project. Among these, two basic designs, in particular, are given primary attention. The first is the ***nonequivalent comparison group design***, which makes use of before and after comparisons for two independent groups that are identical or highly similar to each other in terms of their essential characteristics, where one group is exposed to the treatment (i.e., new metrics) while the other serves as the control group, receiving no treatment. That is, the two groups are not equivalent in terms of the *new metrics* that would have a bearing on the outcomes. The second is the ***one-group pretest-posttest design***, where the same group serves effectively both as the *control* case (before the treatment starts) and as the *treatment* case (after the treatment starts). The latter design option must guard against the counterfactual argument that the two may differ for reasons other than the treatment itself.

Typically, in scientific investigations each member of a population being studied has an equal chance of being chosen. This means, for instance, that each end-item being repaired at a given depot has an equal chance of being included in the study. This means random selection of the individual units of analysis. Moreover, each of these individual end-items has an equal chance of being assigned to various experimental conditions (e.g., different levels of treatment; treatment versus control). Randomization is essential to experimental design in the physical sciences. There are, however, a large class of situations, particularly in the social sciences, where randomization is not possible since real life situations cannot be controlled as in a laboratory. In such situations, it is necessary to make use of "quasi-experimental designs," where individual units are not assigned to various experimental conditions through a random process. While "quasi-experimental designs" lack random assignment of individual units to experimental conditions, they still must meet the same requirements expected of experimental designs involving randomization in terms of drawing causal inferences.

[14] For the sake of completeness, it is assumed that depot-repair, under the influence of new metrics, will not experience a deterioration in its performance in terms of the repair of SRUs (Shop Replaceable Units), thus possibly falling short in its supply of serviceable SRUs, to the extent that depot-repair in fact supplies not only serviceable LRUs (Line Replaceable Units) but also serviceable SRUs to Consolidated Serviceable Inventory (CSI) for shipment to the bases.

In the pilot project, a "quasi-experimental" design is used, since the individual units of analysis in the experiment (i.e., specific avionics end-items being examined) are not selected at random but rather on the basis of deliberate prior choice reflecting certain criteria (e.g., focusing on a pre-selected sample high MICAP[15] end-items *and* a pre-selected sample of supportable end-items) and, further, they are not randomly assigned one or the other of the two comparison groups. Moreover, the two comparison groups are not abstract constructs (e.g., different levels of treatment; treatment versus control) but rather two separate physical sites. By definition, individual units of analysis at each site cannot be randomly assigned to one or the other site. That is, at each site, randomization can occur only in the selection of the individual items for analysis, not in terms of how they are then assigned to one or the other site (i.e., to treatment versus control cases).

Regardless of what type of experimental design is chosen for the pilot project, the analytical objective remains the same. A first-order analytical objective in the pilot project is to test whether th*e treatment* (i.e., new metrics) have statistically significant effects on the measured outcomes, while accounting for the possible effects of both the confounding and control variables on the observed outcomes. If the effects are statistically significant, a second-order objective is to develop reliable measures of the differences *between* the actual observed outcomes due to the *treatment* (i.e., new metrics) *and* what would have happened to the measured outcomes in the absence of the treatment. The formal process pursued is grounded in established scientific principles of experimental design and data analysis.

1. Nonequivalent Comparison Group Design

The first and preferred option is a design which uses two comparison groups, one serving as the treatment group and the other serving as an untreated control group, with pretest and posttest data for both. This is known as the "Quasi-Experimental Design with both Control Groups and Pretests." A detailed technical description can be found in Shadish, Cook and Campbell.[16] This design is often called the nonequivalent comparison group design, in light of the fact that the two comparison groups, while they are considered alike or highly similar to each other prior to the onset of the treatment, become nonequivalent once the treatment starts. *Treatment* here involves the introduction of new metrics. Lack of treatment, or *control*, means an absence of new metrics. That is, the same metrics as before continue to be implemented at the control site, which is not exposed to the new metrics.

In this design, the Ogden ALC avionics sustainment system would serve as the *treatment group*, while the Warner Robins ALC avionics system would serve as the *control group.* The avionics sustainment system is defined as the avionics-related "organic" depot maintenance, repair and overhaul operations, as well as the supporting supplier networks encompassing the Defense

[15]MICAP (mission capability) is a backorder priority designation to denote a condition where an aircraft is not mission capable for lack of a component; the requisition for that component by base-supply is called a MICAP requisition.

[16] See William R. Shadish, Thomas D. Cook, and Donald T. Campbell, *Experimental Quasi-Experimental Designs for Generalized Causal Inference* (Boston and New York: Houghton Mifflin Company, 2002), pp. 135-170.

Logistics Agency (DLA) and commercial providers of new spares, repair parts and components. While the Ogden ALC concentrates on the sustainment of the F-16 avionics system, Warner Robins ALC focuses, among other things, on the F-15 avionics system. The two avionics systems are generally comparable in terms of their state-of-technology and technical system architecture (i.e., federated system architecture, where overall control, and a certain amount of functionality of each avionics subsystem, is delegated to a central mission computer).

For both comparison groups, both *pretest* and *posttest* data (i.e., data to be collected both before and after the start of the treatment) would be developed on all metrics, as well as on other factors of interest. These "other factors of interest" refer to other variables, in addition to the new metrics, that may influence the observed outcomes. These include variables that change concurrently with the changes in the observed outcomes and are known as *confounding* factors, whose respective effects on the outcomes need to be separated from the effects of the new metrics. They also include those factors, known as *control* variables, which refer to key characteristics of the two test sites and of individual units of analysis consisting of pre-selected avionics end-items.

2. One-Group Pretest-Posttest Design

Under this design, the same site (i.e., Ogden ALC) is taken to serve as both the control and the treatment in the experiment. Pretest observations, involving no new metrics, effectively serve as the control. Posttest observations, following the introduction of the new metrics, serve as the treatment. Both pretest and posttest observations refer to all factors of interest, including the new metrics, for the end-items being analyzed which represent the individual "respondents" in the experiment. Data on other end-items, as well as on SRUs, will also be collected to test for any interaction effects.

As pointed out earlier, such a "quasi-experimental" design offers greater simplicity and ease of implementation compared with the two comparison groups design. However, it must have adequate safeguards built into it to make sure that reliable causal inferences can be drawn from it. One possible weakness of such a design is that the pretest and posttest numerical values of the outcome variables may differ not necessarily because of the effects of the treatment but because of other factors not related to the treatment, after properly accounting for any significant changes in the essential characteristics of the Ogden ALC sustainment system.

To provide protection against any threats to the validity of causal inferences from such a design, two additional safeguards can be introduced: adding a second pretest prior to the first, and using a nonequivalent dependent variable. In effect, having two pretests help detect and control for any biases that might exist in estimating the effects of the treatment if only the pretest and the posttest observations were compared. The nonequivalent dependent variable refers to a measure that is not expected to change because of the treatment. For example, introduction of new metrics is expected to affect a particular set of high-MICAP end-items that are difficult to sustain and a set of supportable end-items that are normally quite supportable, in terms of being able to provide the necessary maintenance, repair and overhaul services. However, the numerical values of the metrics for other fairly difficult-to-support end-items are not expected to show any effect due to the introduction of new metrics. One or more of these end-items could serve as the

nonequivalent dependent variable, to show that the observed outcomes are not the result of a more general event or development affecting all types of end-items.

B. Treatment and Control Groups

If the two comparison groups design is adopted in the pilot project, the treatment and control groups (sites), as well as reporting requirements for each, would be defined as follows, while noting, again, that in the event of choosing the one-group pretest-posttest design, the Ogden ALC sustainment system would serve as both the control and the treatment site, as noted above.

1. Treatment Group

The treatment group at OO-ALC consists of four organizations:

- OO-ALC/MALA: The F-16 Avionics Branch, which provides maintenance and repair services on F-16 avionics end-items, consisting of both Line Replaceable Units (LRUs) and Shop Replaceable Units (SRUs).
- OO-ALC/LGF: The organizational entity responsible for all F-16 logistics operations.
- OO-ALC/LGS: The organizational entity responsible for the supply of all "wholesale" repair parts and materials.
- Defense Logistics Agency (DLA): The organizational entity primarily responsible for managing all consumable supplies, including hardware items, used by the military services. Traditionally, DLA buys supply items in large quantities to benefit from economies of scale, stores them in distribution depots until they are requested by the service depots, and then ships them to the appropriate depot facilities. Over the years, DLA's responsibility has expanded from the supply of consumable items and piece parts to include progressively more and more complex aircraft parts and components.

OO-ALC/LGF funds the activities of OO-ALC/MALA (The F-16 Avionics Branch) and, from an organizational standpoint, serves as the "customer" for the repair services provided. It provides provisioning, cataloging, requirements determination, acquisition, distribution, repair and disposal of parts and components, and engineering and technical support services. OO-ALC/LGF also serves as a "retail" supplier to OO-ALC/MALA, providing roughly 10% of all repair parts it needs. OO-ALC/LGS, which is set up as a parallel organization to OO-ALC/LGF, is the main supplier of repair parts and materials, including piece parts. This organization serves as the primary liaison with DLA and has personnel stationed at the Shop Service Center (SSC), which houses the most frequently needed repair parts and manages the shop's workload. The definition of the participating organizations can be expanded to include others, such as contracting and finance, as appropriate.

Currently, the three organizations at OO-ALC are conducting a "work-around" experiment to meet warfighter demand without directly using the EXPRESS system. EXPRESS is the main information and decision-support system the Air Force uses for managing the depot-based component repair operations. More specifically, it prioritizes component repair requirements (i.e., specifying the priority order or sequence in which specific components should be inducted into the repair process) and also guides prioritized distribution of serviceable components to the

operating combat units. The three organizational entities at OO-ALC involved in the provision of avionics-related maintenance and repair services believe that EXPRESS is not meeting warfighter needs correctly. Consequently, they have been together pursuing a "quasi-EXPRESS" process in order to better meet warfighter demand.

The "Quasi-EXPRESS" approach has driven OO-ALC/LGF and OO-ALC/MALA to coordinate their respective activities with each other to determine the quantity and mix of end-items to be produced by the repair process. OO-ALC/LGS is also involved in the "Quasi-EXPRESS" process, as item managers need to be informed of negotiated quantities in order to plan for, acquire and have in place the needed repair-parts and materials. While communications between and across these organizational entities have clearly improved recently through weekly meetings, it may be too early to gauge the degree to which this has benefited the effectiveness of the depot repair process. The new metrics outlined below are designed to further encourage closer communication and cooperation among these organizational entities.

There are problems with current levels of sustainment performance; OO-ALC/LGF and OO-ALC/MALA have contrasting views on the causal factors underlying current levels of performance. While one group points to lack of availability of repair parts as the main source of the problem the other disclaims the parts availability issue and instead cites insufficient manpower cross-training and shop capacity issues the main sources of the problem. The pilot project is being designed to account for these disparate views in analyzing the effects of the new metrics.

As the primary treatment group, the F-16 Avionics Production Branch (OO-ALC/MALA), will be key in evaluating the effects of the new metrics. Currently, its performance is measured on the basis of such metrics as production *versus* "negotiated requirements," productivity measures (yield, indirect labor ratio), and additional metrics required by LGFBR (e.g., depot shop flow time, logistics response time, awaiting parts-parts required (AWP-G), awaiting parts-parts supportable (AWP-F). The LGFBR-required metrics will continue to be observed during the pilot project, even though they will not necessarily be the primary measures of performance in the pilot project itself. However, they are important to analyze to determine the effect of the new metrics on the shop's performance based on existing metrics.

Contacts:

OO-ALC/LG	Col. Audrey L. Wolff, Deputy Director, Logistics Management (To be contacted)
MALA:	Mr. Dave Jensen, Branch Chief
	Capt. Dominic Clementz, Deputy Branch Chief
LGFBR:	Mr. Mike Jackson, LGFBR Section Chief
	Mr. Chuck Vigansky, LGFBR Contractor
LGS:	Ms. Marlene Wright, Division Chief
LGP:	Mr. Jim Lengyel, Acting Division Chief, Government Co-Lead (LSI Enterprise Integration Team)

2. Control Group

The control group in the pilot project is designated as WR-ALC/LYP (Avionics) and related supply organizations. The nucleus of the control group is expected to be the F-15 avionics production shop (OO-ALC/LYPF), WR-ALC/LGS (Depot Supply Division), and the Defense Logistics Agency (DLA). While there are some differences in the avionics end-items repaired at OO-ALC and WR-ALC for the F-16 and F-15, respectively, the workload and workflow processes are quite similar. The F-15 avionics production shop relies on outside organizations to develop accurate predictions of demand. It also relies on the Defense Logistics Agency and other supply organizations for the repair parts and materials it needs. Further discussions with participating organizations will identify and seek the concurrence of other organizations associated with F-15 avionics repair operations. The definition of the participating organizations at the WR-ALC, as well, can be expanded to include others, such as contracting and finance, as appropriate.

The control group organizations are expected to continue providing weekly and monthly data on the existing metrics, as well as data on both confounding factors and control variables, as defined below. In addition, they are expected to provide any narrative statements identifying key issues affecting the metrics for each time period.

Contacts:

WR-ALC/LYP: Col. Wallace ("Skip") A. Collins, Avionics Production Division (To be contacted)
LYPO: Maj. Timothy Nesley, Chief, Avionics Production Division Chief
LYPF: Mr. James Roeder, Chief, F-15 Branch, Avionics Production Division
LYPM: Mr. Jimmy Beeland (To be contacted)
LGSH: Ms. Mary Anne Schubert, Depot Supply Home Office Chief (To be contacted)

C. Units of Analysis

Depot-maintenance provides two types of component repair services: the repair of all unserviceable end-items generated internally within the depot (or in other depots) through the programmed depot maintenance of aircraft (e.g., F-15, C-5, KC-135, etc.) *and* the repair of unserviceable end-items flowing to depot-maintenance from the operating bases. This pilot project focuses on the latter set of components or end-items, which account for much of the repair work done at the depots. The internal demand for component repair services is typically fairly small, predictable, and constant. Hence, internal demand tied to programmed aircraft depot maintenance is assumed to remain invariant during the pilot project and is not explicitly addressed in calculating the effects of the new metrics on the outcome variables, although they are included in analyses of enabling metrics.

Also, depot maintenance, through its various supply organizations, also acquires new spares, such that the flow of serviceable items to the bases from the Consolidated Serviceable Inventory (CSI) at the depots could consist of as mix of repaired items and new spares. Since the key issue is the supply of serviceable end-items to the operating bases, no clear distinction is drawn here

between repaired items and new spares, where the latter play a basically small role in the provision of serviceable items to the bases. More to the point, the intent here is to hold those responsible for the provision of new spares and those responsible for repair services to be held jointly accountable for the outcome of their efforts, which are, by definition, linked together. This treatment should preempt the refrain often heard that satisfying the customer's needs is not solely the responsibility of depot-repair and that any failure in providing the needed serviceable items should be levied upon the supply chain manager.

The units of analysis in the pilot project refer to specific pre-selected components (end-items; line replaceable units – LRUs). Two categories of end-items are defined for analysis: MICAP avionics end-items (those components that are in particularly critical demand, based on past data on both MICAP incidents and MICAP hours) *and* supportable avionics end-items (those components that can be repaired to meet normal customer demand for serviceable items).

The end-items in these two categories reflect the proposition that MICAPs and backorders are the items most required by the warfighter on the flight line. The first five end-items that are selected represent the top five MICAP end-items during the period of July 2001 to June 2002. In addition to these specific end-items, OO-ALC/MALA wants to monitor a particular Shop Replaceable Unit (SRU), the Low Noise Amplifier (LNA), which is a major part of the MLPRF end-item and which represents particularly serious supportability problems. The last six end-items are deemed "supportable" end-items recommended for analysis by OO-ALC/MALA. "Supportable" means the shop has available carcasses, the required production capacity, and needed parts and funding for repair.

<u>Group of MICAP End-Items (End Items Repaired at Ogden ALC)</u>

1. *Radio Frequency Shop*

- MLPRF –1270-01-233-0011WF – Modular Low-Power Radio Frequency
- Antenna – 5985-01-212-2950WF
- LPRF – 1270-01-102-2962WF – Low-Power Radio Frequency

2. *Displays and Indicators Shop*

- MFD – 6625-01-193-8861WF – Multi-Function Display

3. *Microwave Shop*

- DMT – 1270-01-238-3662WF – Dual Mode Transmitter
- LNA – 1270-01-132-6867WF – Low Noise Assembly (SRU)

<u>Supportable End-Items</u>

1. *Displays and Indicators Shop*

- HUD EU – 1270-01-468-8658WF – Heads-Up Display Electronic Unit

- MSC – 5826-01-052-1945NT – Mode Select Coupler

2. *Computer and Inertial Shop*

- DFLCC – 6615-01-448-6152WF – Digital Flight Control Computer
- RGA – 6615-01-042-7834WF – Rate Gyro Assembly

3. *Processor and Pneumatics Shop*

- JRIU – 5998-01-080-3978WF – Jettison Remote Interface Unit
- MRIU – 1290-01-109-1499WF – Missile Release Interface Unit

These predetermined end-items in both categories will be matched with similar end-items repaired at the WR-ALC avionics production shop.

Although the pilot project will focus directly on these pre-selected individual end-items to measure the effects of the new metrics, data on all other MICAP and backorder items (as two broad groups) will also be developed to test for any positive or negative effects of the new metrics on these two groups of end-items. The specific question of interest here is to see whether depot-repair, by concentrating on the repair tasks related to the pre-selected items -- because they are being directly monitored in the pilot project -- may end up placing less emphasis on other end-items.

D. Time Period

The time period for the first phase of the pilot project will be one calendar year. It is important to give the participating organizational entities sufficient lead time prior to the initiation of the pilot project so that they can review and approve the pilot project implementation plan and put in place preparatory steps for launching the pilot project. Also, the pilot project should be reviewed at the conclusion of the first six-month period in order to make any mid-course corrections in executing the pilot project, should that be considered desirable.

At the conclusion of the pilot project, the results will be evaluated and plans for further pilot projects will be developed and implemented, as appropriate. One option might be to evaluate the effects of an expanded treatment regime to include both new metrics and the introduction of key lean practices into depot repair operations and the supporting supplier base.

VI. NEW METRICS AND RELATED DATA REQUIREMENTS

This section focuses on the new metrics and related data requirements. The latter include data on confounding factors, control variables and other measures of interest, as well as data on existing metrics. Both pretest and posttest data will be collected for the new metrics, confounding factors and control variables on a weekly (if possible) and monthly basis. Similarly, data will continue to be collected and made available on the existing metrics currently being used by the Air Force in managing the sustainment system. Such data are required for conducting a rigorous evaluation of the validity and benefits of the new metrics. Although the collection of the required data may

entail additional investment in the near term, the anticipated results should provide significant benefits far outweighing any incremental near-term data collection costs.

A. New Metrics

New metrics are categorized into two main groups: *outcome metrics* and *enabling metrics*. *Outcome metrics* represent, for the purposes of the pilot project, delivery of value to the customer. They are customer satisfaction metrics. They gauge how effectively the customer's urgent and normal needs are met, how well they are met (e.g., in terms of product quality, customer-wait-time), and how cost-efficiently they are met (e.g., average cost of repair). *Enabling metrics* gauge how well the sustainment system performs various processes, functions and practices – by making sure that the organization is doing the "right job" as well as doing the "job right" -- to deliver the defined outcome metrics benefiting the customer,

1. Outcome Metrics

The concept of outcome metrics, derived from the idea of delivering value to the customer, can be further generalized to encompass the creation and delivery of value to all stakeholders. [17] In this broader conceptualization, stakeholders would include, for instance, the Department of Defense and the Air Force at the "corporate" level, in the sense of delivering efficient, reliable, and responsive maintenance and repair services. Stakeholders would also include the warfighter, the workforce, and the supplier network, all linked together through the construction of a robust value proposition serving as the basis for creating and delivering value.

For the purposes of this pilot project, a narrower definition of the "customer" is adopted, focusing directly at the "bases." It is assumed that improving customer satisfaction at the base-level will simultaneously improve the delivery of value to other stakeholders as well (e.g., to the warfighter, to the Air Force at the "corporate" level). Nevertheless, to demonstrate how the new metrics can lead to improvements in the delivery of value to these stakeholders, the pilot will provide a link between *incremental* improvements in depot-repair performance levels and resulting *incremental* improvements in flight line performance metrics (e.g., fully-mission-capability rates).

The following customer need satisfaction metrics, which also represent the new *outcome metrics*, are identified (for each targeted end-item to be analyzed in the pilot project):

- ***Urgent customer requirements satisfaction rate (UCRSR):*** This is defined as the ratio of total number of serviceable end-items provided[18] during a given period *to* total number of high MICAP items as defined at the base level.

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[17] For a discussion of a framework for value creation and delivery at the enterprise level (e.g., program enterprises, multi-program enterprises, the US aerospace enterprise) refer to Earll Murman, *et al.*, *op cit.*

[18] The word "provided" is used here deliberately, to convey the idea that the supply of serviceable end-items from the Consolidated Serviceable Inventory (CSI) at the depot to the operating bases consists of both repaired items and new spares. The upshot of this is that the metric is chosen to foster closer cooperation between the "fixer" and the supply organizations, to help integrate investment decisions concerning the procurement of new spares more closely into the depot-repair process and, hence, into the resupply pipeline to meet customer needs on a timely basis.

- ***Normal customer requirements satisfaction rate (NCRSR):*** This is defined as the ratio of the total number of serviceable end-items provided during a given period *to* total number of backorders issued by bases.

- ***Weighted customer requirements satisfaction rate (WCRSR):*** This is defined as a weighted average of UCRSR and NCRSR. The assigned weights signify the relative importance of each and are numerically estimated by quantifying the relative importance that is implicitly attached to each, based on previously negotiated quantities through the "Quasi-EXPRESS" experiment. These weights are taken as a first-approximation of the true weights that could be estimated, if true customer (warfighter) needs were known. Neither EXPRESS nor the "Quasi-EXPRESS" approach is likely to serve as the most reliable (true) measures of actual customer demand. In the absence of such "true" estimators of actual customer demand, the "Quasi-EXPRESS" results are taken as second-best "true" estimators. In the case of the WR-ALC, to the extent that induction decisions are driven by EXPRESS, previous inductions of MICAP items and backorder items can be used to derive the "revealed" weights attached to each category of customer demand.

- ***Cost:*** This metric is designed to measure the actual (incurred) cost of the maintenance and repair services provided for a given end-item by serial number. This requires the determination of the actual full costs of both materials and labor, as well as the cost of utilization of capital (plant and equipment) which is typically built into the prevailing overhead rates. For the purposes of this metric, it would suffice to use the prevailing (already negotiated) direct labor, overhead and general and administrative (G&A) rates. However, in computing labor hours, it is important to capture the total number of actual labor hours incurred rather than standard hours. Moreover, actual labor hours should include accumulated labor hours for repairing a particular end-item across all shops, including labor hours required to repair the SRUs embedded in that end-item.

  During the pilot project, it is assumed that for each serviceable end-item the customer will continue to be charged at prices reflecting previously-negotiated rates, even though the "actual cost" figures computed as just noted might be somewhat lower, reflecting possible efficiency gains due to the introduction of new metrics. Comparing the "business-as-usual" prices charged to the customer reflecting previously-negotiated rates *with* the actual incurred costs during the pilot project, where the latter might entail lower prices due to possible expected efficiency gains, would help determine answers to the following two questions: (a) would the pilot project result in any cost savings to the customer; and (b) what would be the magnitude of such cost savings?

- ***Product quality:*** This metric measures the percent of the total number of serviceable end-items produced by depot-repair (and shipped to CSI for distribution to the operating bases) during a given period that are found to be defective. There are two ways of computing this metric for a particular end-item. The preferred way would be to define the *denominator* as the total number of that end-item "produced" by depot-repair during a given period and shipped as a serviceable item to Consolidated Serviceable Inventory (CSI). The numerator would be slightly complicated to compute. It would involve tracking each one of those

serviceable items by serial number and count how many of them had Quality Deficiency Reports (QDRs) filed against them, upon testing at the base-level, and then shipped back to depot-repair. Next, it would be necessary to count how many of those QDR items re-tested by depot-repair were actually found to have quality defects. This final number of items found to have defects – whatever type or number of defects within each end-item tested – would then represent the numerator.

A less cumbersome but also less accurate way would be to simply take the total number of a given end-item produced during a given period, as the denominator, and take, as the numerator, the number of that same end-item (with a QDR attached to it) which is re-tested at depot-repair during the same period and found to be defective. Another way of computing the numerator, for a given end-item, is to count the total number with a QDR designation re-tested at depot-repair *minus* the total number that is designated as No Fault Found (NFF). Of course, in using this second method, the serial numbers of the end-item in question that make up the numerator will not match the serial numbers of those that make up the denominator. This is another way of saying that the time-profiles of the serial numbers in the numerator and in the denominator are quite different. This may distort the quality metric that is computed, particularly when depot-repair production during a particular accounting period has dropped precipitously (e.g., in July, 2002) compared with production levels during previous periods generating those very same quality defects.

- ***Customer Wait Time:*** This metric measures the total elapsed time in hours (including pick, pack and ship time, total transportation time including any in-transit wait time, unpacking time) for each pre-selected end-item from the moment a requisition for it is issued by the bases until the time a serviceable end-item is received at base supply and is, in fact, available to base maintenance upon request. Total elapsed time is used to encourage better coordination along the pipeline to minimize the time it takes to provide the needed serviceable end-item to base supply so that it is available to base maintenance or for delivery straight to the flight line. In this definition, "customer" is defined, for all practical purposes, as "base supply." It is important to note that this definition differs from that just adopted by the Air Force sustainment system which measures "customer wait time" as the total elapsed time between when base maintenance requests a serviceable end-item and when base supply makes that item available for use. It can be argued that improving the "customer wait time" as proposed for the pilot project would, in fact, nullify the need for the second definition.

The implementation of these new *outcome metrics* (customer satisfaction measures) includes the concurrent adoption of a number of new operating rules. These new operating rules will include, but not be limited to, the following:

- The F-16 Avionics Production Branch (OO-ALC/MALA), working through the relevant Shop Service Centers (SSCs), will be able to place orders for repair parts and materials ahead of induction, for the pre-selected end-items that are being directly studied in the pilot project.

- OO-ALC/MALA, LGF, LGS, and DLA will work jointly through meetings on a weekly basis in planning repair requirements, procurement of the necessary repair parts and

materials, and any pre-kitting activities in support of the MRO operations related to the pre-selected end-items.

- LGF and LGS, working in concert with the relevant SSCs, will be authorized to acquire the necessary repair parts and materials directly from commercial suppliers when and if DLA is considered unresponsive to the data availability needs at depot-repair on a timely basis.

- LGF, LGS and DLA, working together in close cooperation, will be authorized to streamline contracting processes for the repair parts and materials required for the pre-selected end-items, in order to bring under contract outside commercial suppliers in the shortest time possible; they will further be authorized to enter into long-term partnerships and strategic alliances with selected suppliers.

- DLA will be authorized to acquire repair parts and materials for any of the pre-selected end-items without having to apply the Economic Order Quantity (EOQ) method, to ensure that the required repair parts and materials are made available to depot-repair when needed on a timely basis. Further, DLA will refrain from the practice of eliminating stocks of parts and materials not used during the previous two years for the specific pre-selected end-items.

- The F-16 Avionics Production Branch will be waived from having to show "sales" benefits for a number of the pre-selected end-items, chosen at random, to allow all shops to concentrate on improving their performance on these particular end-items rather than on covering its costs. This is expected to motivate depot-repair to strive to achieve system-wide optimization rather than local (sales) optimization. The implementation of this operating rule will be important in testing two of the main hypotheses outlined earlier.

It is expected that improvements in these *outcome metrics* (customer satisfaction measures) will impact the warfighter directly: (a) by leading to a *reduction* in TNMCS (Total Not mission Capable for Supply), through improvements in base-supply of serviceable items, that should directly help to increase the FMC (Fully-Mission-Capable) rates; and (b) by promoting greater efficiency in base-repair operations – through reduced cannibalization in light of greater availability of serviceable items, such that the available resources can be put to more productive pursuits – which would tend to reduce the TNMCM (Total Not Mission Capable for Maintenance) rates and thereby increase the FMC rates.

2. Enabling Metrics

Enabling metrics refer to those few pivotal metrics that drive an enterprise's overall effort at various levels towards the achievement of its overarching goals and objectives. These metrics are operative at multiple levels and across organizational processes and functions as well as across organizational boundaries. They are designed to motivate people to strive to achieve global optimization across the enterprise. Well-designed enabling metrics foster a culture that both motivate and reward efforts for doing the "right job" as well as for doing the "job right." This means not only making the right choices but also allocating the right types and levels of effort to performing the selected projects or tasks. Most metrics only concentrate on "doing the job right" (e.g., at minimum cost, eliminating waste), losing sight of the organization's central mission to

provide the right types of products and services necessary for delivering value. Well-designed enabling metrics also overcome short-term orientation, risk aversion, parochialism, "not-invented-here" syndrome, and related behavioral traits that undermine the enterprise's efficiency and effectiveness. Among the enabling metrics, some can be identified as "gatekeeper" metrics in the sense that they exert significant leveraging influence on the outcome metrics.

For this pilot project, the following enabling metrics are proposed:

- ***End-item shopfloor flow time:*** This metric is already being tracked by the Air Force sustainment system. Of greater interest here, however, is tracking the *variance* in shopfloor flow time for the pre-selected end-items. Variance, a statistical concept, measures variability. The idea is to encourage the depot repair process to minimize variability. This is a central idea from Six-Sigma thinking and practice; it is also historically an integral part of lean thinking and is an important driver continuous quality improvement[19]. The depot repair process inherently exhibits considerable variability that is arguably greater than that observed in normal manufacturing operations. Still, such a metric motivating continuous reduction in variability would foster more standardized workflow processes, improved worker training, self-inspection, and other desirable lean practices. The end result of reducing variability is expected to be shorter mean shopfloor flow time, which would translate into increased capacity, enhanced capability, higher productivity and greater throughput.

- ***Cost of maintenance and repair:*** This metric, as well, is currently being tracked, most likely in the form of "standard" cost, reflecting previously-negotiated rates. The main interest in the pilot project is in "actual" incurred cost, as noted earlier in connection with the discussion concerning outcome metrics. Of greater interest here is the variability (variance) in the actual cost of performing maintenance and repair services for each end-item. Reducing variation in the cost of repair services would result in lower average costs, as many Six Sigma enterprises have already found out. Also, such a metric placing emphasis on reducing cost variation would foster the adoption of basic lean practices for identifying and eliminating all sources of

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[19]Six Sigma, which has its roots in the application of probability theory to statistical quality control, has widened its scope in recent years to encompass an integrative management tool for achieving continuous improvement across the entire enterprise. The relationship between Six Sigma and lean thinking can be brought into sharp relief in the context of production operations: while Six Sigma stresses *quality improvement* through elimination of all sources of variation, lean thinking concentrates on *speed* through continuous *defect-free flow* across the entire enterprise value stream. Viewed at the enterprise level, Six Sigma is an important enabler of lean thinking. For a comparative discussion of lean thinking and Six Sigma, see Kirkor Bozdogan, "Lean and Six Sigma: An Overview," Draft Working Paper, Massachusetts Institute of Technology, Lean Aerospace Initiative (July 24, 2002), 10 pp.

For further information on lean thinking, see, for example, Murman, et al., as well as James Womack, Daniel Jones and Daniel Roos, *The Machine that Changed the World: The Story of Lean Production* (New York: Rawson Associates, 1990; and James Womack and Daniel Jones, *Lean Thinking* (New York: Simon & Schuster, 1996).

For further information on Six Sigma, see, for example, Mikel J. Harry and J. Ronald Lawson, *Six Sigma Producibility Analysis and Process Characterization* (Reading, MA: Addison-Wesley Publishing Company, 1992); Peter S. Pande, Robert P. Neuman and Roland R. Cavanagh, *The Six Sigma Way* (New York: McGraw- Hill, 2000); and George Eckes, *The Six Sigma Revolution* (New York: John Wiley & Sons, Inc., 2001).

waste (e.g., through value stream mapping and analysis; standard work; preventive maintenance; 6S techniques; mistake proofing; cross-training; *kaizen* events).

- ***Productivity:*** This metric measures the total number of a given Line Replaceable Unit (LRU) or end-item (in physical units, not sales) produced by depot-repair per 100 labor-hours (or per 1000 labor-hours) utilized by all workers to repair that end-item, from that end-item's initial induction into the shop to its shipment as a serviceable item to Consolidated Serviceable Inventory (CSI). In computing this metric, it is important to accumulate the total number of labor hours actually incurred across all shops in connection with the maintenance and repair of a particular end-item. This would include labor hours used in repairing all shop-replaceable units (SRUs) embedded in a given end-item. An alternative, acceptable, way of capturing this metric would be to express it as the total (cumulative) number of labor hours utilized to produce one unit of a particular end-item.

  This metric is not intended to gauge the overall quality of the effort being exerted by depot-repair but rather to encourage more efficient allocation of the available resources (both labor and capital) to the performance of the tasks at hand. There is a rich history in economics addressing the issue of measuring productivity of firms, industries and countries as the ratio of output *to* all types of factor inputs employed (labor, capital, materials) – by using "total factor productivity" measures. The focus here is on a fairly simple "single factor" productivity measure. Thus, for the purposes of this pilot project, a basic measure of "labor productivity" is considered sufficient, while controlling for the "up-time" availability of the testing equipment.[20] The number of labor hours actually employed is not adjusted for unscheduled work-stoppages due to equipment failure in order to motivate depot-repair to put greater emphasis on preventive maintenance.

- ***Responsiveness:*** This metric measures the degree to which depot-repair is responsive to objectively-determined, resource-unconstrained, customer demand that it is supposed to meet.[21]The metric is measured as the ratio of the *required Takt time* to the *observed Takt time*. Takt time is a concept from lean production indicating the desired tempo at which the production system should operate to meet the pace of customer demand. For example, if depot-repair must produce a serviceable end-item of a particular type every 15 hours in order to meet the customer's rate of demand for this end-item, this is the required Takt time. If the actual or observed Takt time is instead 30 hours, then depot-repair responsiveness is 0.50 (i.e., 15 hours ÷ 30 hours).[22] A plausible interpretation of such a responsiveness rate is that the production facility is simply not being sufficiently responsive to the tempo of customer

[20] This is done by introducing a control variable which gauges, for the pre-selected end-items, the depot-repair wait-time due to unscheduled downtime in testing equipment as a percent of total shopfloor flow time.

[21] In this discussion, contract repair is assumed to be an extension of depot-repair. Thus, the responsiveness metric is intended to capture the combined responsiveness of both "organic" depot-repair and contract repair.

[22] How such a measure can be computed for a given product can be quickly illustrated as follows. Suppose the total scheduled production time for a facility during a given month is 280 hours (i.e., (2 shifts/day) x (7 effective working hours/shift) x (5 days/week) x (4 weeks/month)). If customer demand (rate of consumption) is 14 units per month, then the *required Takt time* is 20 hours (i.e., (280 hours/month) ÷ (14 units/month)). Suppose, however, that the production facility is actually producing only 7 units/month, rather than 14 units/month. Then, the *observed Takt time* is 40 hours/unit/month (i.e., (280 hours period) ÷ (7 units/month)). Thus, the ratio of the *required Takt time* to the *observed Takt time* is 0.50 (i.e., (20 hours/unit/month) ÷ (40 hours/unit/month).

demand for the particular product in question. This could be the result of a combination of factors, such as lack of visibility into the volume and time-profile of customer demand, sheer inefficiency in production operations, and presence of barriers to greater efficiency. The production facility can improve its responsiveness only by tackling these factors head-on.

The responsiveness metric as defined is important because it gauges how closely depot-repair is operating with reference to the required (or target) Takt time. The gap between the target Takt time and the currently observed Takt time can be explained by a combination of factors, including resource constraints, the various policy and regulatory barriers under which depot-repair operates, and funding constraints that it faces.

The computation of the *required Takt time* for depot-repair calls for a definition of the true customer demand for depot-level component repair. This can be estimated by summing up total demand from the various sources. One source of demand, for instance, is the demand associated with aircraft brought into the depot for either programmed depot maintenance or upgrade. Another source of demand is foreign countries which have fleets obtained under foreign military sales (FMS). The largest source of demand is base-level demand, which encompasses the operating combat units (e.g., Air Combat Command- ACC; Pacific Air Forces –PACAF; United States Air Forces Europe – USAFE; Air National Guard – ANG; Air Force Reserve --AFR), as well as a number of special units (e.g., Air Force Materiel Command – AFMC; Air Education and Training Command– USAFE). Total demand from the bases, for instance, can be estimated by considering the total number of end-items that are designated as "Not Repairable This Station" (NRTS) at the base-level.[23] This represents the total volume of unserviceable (or reparable) end-items depot-repair is expected to turn into serviceable end-items for shipment back to the bases, assuming that base maintenance will be fully able to repair all "Repairable This Station" (RTS) items, for which the necessary repair parts and materials would be made available by depot supply.

If depot-maintenance -- including contract repair support by commercial providers-- keeps turning out the requisite number of serviceable end-items, base-supply will have a steady-state resupply of these serviceable items, ensuring sustained FMC rates reflecting prevailing norms of readiness. In reality, of course, not all of the MICAP and backorder items get repaired, primarily because of funding constraints. Further, of those that are inducted into depot-repair, some may have higher priority rating than others and are given higher priority attention, and others may have to wait there for long periods of time due to lack of availability of the needed repair parts and materials (i.e., these items become designated as AWP-G, assets waiting for repair parts for which backorders have been placed).

[23] An alternative way of gauging true demand is to count the total number of MICAP items and backorder requisitions received by the depot from the operating bases. The resulting total should approximate the total number of NRTS items. This follows from the fact that at the base-level each unserviceable asset is either designated as "Not Repairable This Station" (NRTS) and sent to depot-repair, or kept for repair by base maintenance, or condemned by base supply. Normally, each unserviceable asset is turned into base supply in exchange for an available serviceable asset and base supply originates a requisition for each such unserviceable asset. Thus, the total number of requisitions (for both MICAP items and backorder items) should approximate the total number of NRTS items.

Under such a scenario, the depot-maintenance system would simply not be able to supply the required number of serviceable items, especially while it is underfunded to invest in new spares to replace condemnations. Then, there would result, by definition, a deficit of serviceable end-items. As long as such a deficit continues, the combat forces would experience degradation in terms of their FMC rates. Such a scenario would seem to approximate pretty closely the current state of affairs. Thus, in computing the observed current Takt time, total demand can be taken as the demand resulting form the "Quasi-EXPRESS" negotiation process currently being used at the Ogden ALC (i.e., "negotiated demand"). It is important to note that this "negotiated demand" would, in all likelihood, differ, perhaps significantly, from the actual or real demand. The reason is that the "negotiated demand" reflects not the real needs but what is feasible to provide in light of the existing funding and other resource constraints.

- ***End-item repair parts combined fill rate:*** This metric measures the repair parts and materials fill rate for a given end-item, taken together, rather than for individual parts needed for repairing that end-item. The importance of such a metric can be demonstrated by using a simple example. Suppose, for instance, that a given end-item requires parts A, B, C and D in order to repair it. Suppose, further, that the issue effectiveness rate (or stockage effectiveness rate) for the individual parts are, respectively, 0.80, 0.90, 0.85, and 0.95, such that the supply organization can make the claim that its performance is very good to excellent, under the circumstances. A more objective view, however, would cast doubt on such a claim. The reason is that the joint probability of the availability of these parts, taken together, to depot-repair at a given point is, roughly speaking, more like 0.60, which is a far cry from anything that depot-repair should find acceptable. It can be seen, in somewhat more technical terms, that if the respective probabilities of the availability of the required parts are $P_A= 0.80$, $P_B= 0.90$, $P_C= 0.85$, and $P_D= 0.95$, then the joint probability of the combined availability of all four parts taken together at a given point is the intersection (multiplication) of the respective probabilities (i.e., $(0.80)x(0.90)x(0.85)x(0.95)= 0.58$).

  In the above example, if parts A, B, C, D are in fact frequently failing parts, then having all four available to depot-repair would lead to a significant improvement in the efficiency and effectiveness of the depot-repair process. To the extent that these parts are currently supplied by separate supply organizations, such a combined fill-rate metric would provide a strong incentive for them to cooperate. A particularly desirable outcome would be if they synchronize their activities and provide pre-kitting of the required repair parts and materials.

  This metric is similar in concept to the "Equipment Repair Order" (ERO) fill rate metric introduced by Fricker and Robbins for employment by the US Marine Corps.[24] The ERO fill rate metric, which is limited to critical repairs, measures the percentage of all critical repairs that receive all of their high-priority parts from local supply. Fricker and Goodhart, using actual Marine Corps data, have found through simulations that employing the ERO fill rate metric, along with two new techniques, can lead to significantly improved supply system

[24] Ronald D. Fricker, Jr., and Marc Robbins, *Retooling for the Logistics Revolution: Designing Marine Corps Inventories to Support the Warfighter* (Santa Monica, CA: RAND, MR-1096-USMC, 2000).

performance.[25] The metric proposed here for the pilot project differs from the ERO fill rate in the sense that it is focused on all or most frequently failing parts for each individual end-item, rather than focusing on specific repair tasks that are considered critical repairs.

- ***Supplier delivery performance:*** Currently the Air Force sustainment system lacks adequate measures of supply chain performance. This metric is proposed as a first step to gauge the performance of the supplier network supporting the sustainment system. The metric quantifies the "order-to-delivery" time for repair parts and materials obtained from suppliers, by using three related performance measures: elapsed time required from order-to-delivery for 50% of all repair parts and materials requisitioned; elapsed time required from order-to-delivery for 75 % of all repair parts and materials requisitioned; and elapsed time required for order-to-delivery of 95 % of all parts and materials requisitioned.

B. Confounding Factors

Confounding factors are those variables that may be correlated with the outcome variables -- or that may covary with the outcome variables -- such that there is the risk of attributing the observed outcomes to the treatment itself when in fact they may have been caused by these other factors that change in the same direction as the treatment factors. A list of the confounding factors that are of particular interest in this case study is given below.

- ***Burn rate:*** This metric measures the total amount of dollars actually spent on depot-repair during a given period. It is conjectured that higher levels of spending can lead to increased numerical values for the outcome variables, where such effects may be confounded with the treatment effects. Even though the burn rate, as defined, relates to all end-items going through depot-repair, it is reasonable to expect that higher levels of aggregate spending may also well affect the performance of depot-repair on the specific groups of end-items being studied.

- ***Labor hours:*** All else remaining equal, allocation of a greater number of labor hours, while keeping constant the capital stock (e.g., testing equipment capacity) may well influence the outcome variables. This metric is defined as the total number of labor hours (both normal shifts and overtime) actually allocated during a given period, computed separately for the LRU shops, the SRU shops, and the combined total for the entire facility. It is conjectured that the allocation of a greater level of labor effort in the aggregate could influence the levels of effort more specifically directed to the end-items being studied, thus affecting the outcome metrics for these end-items.

- ***Testing rework:*** One of the ways in which the operating bases can influence the efficiency and effectiveness of depot-repair is the extra workload they may cause depot-repair to undertake, thus resulting in misallocation of scarce depot-repair resources. An example is the practice of testing "serviceable" end-items shipped to base supply from CSI, after they are produced by depot-repair, which are found to have discrepancies. These items are then sent

[25] Ronald D. Fricker, Jr., and Capt. Christopher A. Goodhart, "Applying a Bootstrap Approach for Setting Reorder Points in Inventory Systems," *Naval Research Logistics*, Vol. 47, No. 6 (September 2000).

back to depot-repair, where they are re-tested. Typically, in a majority of the cases, depot-repair classifies these re-tested items as "No Fault Found," which means that the depot is unable to replicate the discrepancies found at the base-level and that these items are indeed serviceable. To the extent that depot-repair, compared with the bases, has older testing equipment or test equipment with different capabilities, such discrepancies may be unavoidable. Nevertheless, a considerable amount of scarce depot-repair resources are claimed by the end-items that are re-tested. Regardless of the testing results (i.e., No Fault Found or quality defects found), the amount of this workload can have a serious impact on the overall efficiency and effectiveness of depot-repair. An increase or decrease in the total number of end-items that are re-tested at depot-repair during a given period can impact the overall performance of depot-repair in terms of the outcome variables. Therefore, a testing rework factor is proposed as a confounding variable. For the purposes at hand, this factor measures the total number of re-tested end-items as a percent of all end-items inducted into depot-repair.

C. Control Variables

Control variables refer to specific characteristics, situational factors, policies and procedures and other attributes that differentially affect the groups, or individual units of analysis, that are being studied in the experiment. For example, two comparison groups may differ sharply in terms of the age composition, educational attainment, skill levels, or unionization of the workforce. One group may have much more modern testing equipment than the other, or may be comparatively more advanced in using information technologies. Such differences might have differential impacts on the performance of the two comparison groups. The objective is to equalize the two groups in terms of these observed differential characteristics by holding the most important of these factors constant or as invariant as possible. A list of the control variables that are of particular interest in this pilot project is given below.

- ***Information access:*** The Depot Repair Information Local Server (DRILS) system now operational at the Ogden ALC avionics repair facility provides direct visibility into the repair history of specific end-items inducted into repair as well as repair parts usage for each end-item. For example, the DRILS system can be used in troubleshooting particular serial numbers on all end-items. By creating a serial number history, "red-flags" are put in place for certain serial numbers that are inducted, on average, more often than others. This helps to identify continuing problems with certain repair parts and manufacturers, for instance

    DRILS is not yet available for use at the Warner Robins avionics facility. Thus, this control variable is proposed to account for the apparent differences between the two repair sites, in terms of information availability and access, that would have a differential impact on their respective performance. To control for these differences, the following "information access rating system" is offered:

  Level 1: No ready access to prior repair history and parts usage for any given end-item for any backshop.
  Level 11: Only hardcopy/logbook access to any given end-item for any backshop.

Level III: Real-time, technician-entered, electronic access for a limited number of end-items (< 25%) for any backshop.

Level IV: Real-time, technician-entered, electronic access for a majority (25% to 85%) of end-items for all backshops.

Level V: Real-time, technician-entered, electronic access for all end-items for all backshops.

- ***Test equipment availability:*** This variable controls for any differences between the two repair facilities in terms of the availability of test equipment for performing the required testing tasks. It is defined as the total number of hours a given end-item has to wait of wait time for testing services due to unscheduled equipment downtime as percent of the total shopfloor flow time for that end-item.

- ***Workforce experience:*** This measure is intended to control for any differences between the comparison groups in terms of the level of experience of the technical workforce. The metric proposed here is the average number of years of on-the-job work experience of the technical workforce in the LRU shops, in the SRU shops, and for the facility as a whole.

- ***Worker training:*** This measure is intended to control for any differences between the comparison groups due to different levels of exposure to basic lean principles and practices. It is measured as the cumulative percentage of all workers who have had at least two days of formal classroom instruction and training in basic lean practices. These practices encompass, for example, kanban-based "pull" systems for just-in-time (JIT) production, value stream mapping and analysis, 6S (Establishing Visual Order), Kaizen events, standard work, Takt time, load leveling, mistake proofing, root cause analysis, single-piece flow, cellular design, total preventive maintenance, process control (including Six Sigma principles) and related lean methods.

- ***Cellular production:*** This measure represents another variable for controlling for any differences between the comparison groups in terms of their use of lean practices. This particular measure is chosen as an illustrative case of lean implementation. It is defined as the percentage of all SRUs that are repaired by using cellular manufacturing principles and methods. It is conjectured that any improvements in SRU repair will have a wider leveraging effect on the LRU repair tasks, since a considerable part of the challenge in LRU-related repair involves the timely availability of serviceable SRUs from the SRU shops. It is hence thought that, all else remaining equal, lean deployment in connection with SRU-related repair tasks can be taken as a fairly reliable gauge of the extent to which lean practices have been adopted in avionics MRO operations.

- ***Resource constraint:*** This metric is intended to account for any significant differences between the two comparison groups in terms of the level or severity of the resource constraints they may be facing in the course of the pilot project. For example, if one site is much more resource-constrained than the other, than their respective performance levels need to be adjusted for such differences. One measure of the degree of resource constraint faced by each site is the percent of all reparable end-items at Consolidated Repairable Inventory (CRI) that is not inducted into depot-repair due to any number of resource constraints (e.g.,

funding limitation, lack of available parts, shop capacity).[26] For example, if there are 100 NRTS items at CRI of which 5 had to be condemned, 95 end-items are available for induction into depot-repair. Of these, let us assume that 20 are not inducted, due to a combination of resource constraints. Then, the numerical value of the resource constraint measure proposed here would be 0.21 (i.e., 1.0 – 75/95).[27] It is conjectured that a higher constraint factor would have a larger adverse impact on performance, all else remaining equal. Hence, this control variable is intended to equalize the performance of the two comparison groups for any observed differences in terms of the severity of constraints under which they may be operating.

- ***Induction policies:*** Differences in induction policies may impact the performance of the two sites in different ways. The Ogden ALC is following a "Quasi-EXPRESS" process reflecting a negotiated production level and an induction policy supporting the production of the negotiated output levels. This means substantially reduced utilization of the prioritization scheme determined by EXPRESS on a daily basis. Meanwhile, the Warner Robins ALC may still be operating in accordance with the prioritization process provided by EXPRESS. This control variable is intended to account for such differences in induction policy. A proposed way of quantifying this factor is the total number of end-items inducted into depot-repair bypassing EXPRESS as a percent of all end-items inducted into depot-repair.

D. Other Data Requirements

The successful execution of the pilot project will require the following additional data:

- ***Current metrics:*** Data on all currently used metrics, for all end-items, will continue to be developed and will be made available for use in the pilot project.

- ***Cannibalization and robback data:*** Data on both cannibalization and robback practices will be required for each of the selected end-items being studied in the pilot project to gauge the effects of new metrics on the extent to which cannibalization and robback practices. Data will be required on both cannibalization and robback *incidents* and *hours.*

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[26] The Supportability Module of EXPRESS, which is the central information and decision-support system used by the Air Force sustainment system for the prioritization of depot-repair tasks as well as for the distribution of serviceable items to the operating bases, contains a Supportability Module which operates on all EXPRESS-determined priority repair requirements. The Supportability Module applies effectively a screening process testing for the availability of four types of resources in the following order: carcasses, repair dollars, component parts, and shop capacity. If an end-item on the EXPRESS priority list fails to meet any of these resource availability tests, it is not inducted into repair. For a more detailed description, see Maurice Carter and Ronald W. Clarke, "EXPRESS Planning Module," *Air Force Journal of Logistics*, Vol. XXIII, No. 4 (Winter 1999), 23-26.

[27] The total number of reparable end-items that can be inducted into depot-repair, as defined here, differs somewhat from that calculated in EXPRESS. The total number of carcasses available for induction is estimated in EXPRESS as the sum of all carcasses on-hand (i.e., NRTS items already at CRI *less* those condemned) *plus* those in the in-transit pipeline to the depot *plus* those that are expected to be sent from the operating bases to the depot over the planning period. See Carter and Clarke, *Ibid.*, p. 25.

As noted earlier, such additional data will be needed for analytical purposes only during the pilot project to validate the new metrics. This should help save excessive data collection costs in the future.

VII. PROJECT STRUCTURE

The pilot project operational team consists of those involved with avionics production at both OO-ALC and WR-ALC and, more broadly, encompasses all of the participating organizations. In fact, the pilot project is expected to be "owned" by the principal participating organizations, which will be responsible for its execution based on agreed-upon ground rules and operating procedures. The government support staff at OO-ALC and WR-ALC is expected to help collect the metrics and related data required for the pilot project. The role of the MIT LSI researchers will be to provide technical support and data analysis. It is expected that the participating organizations will be kept abreast of on-going pilot project outcomes based on analyses of the data being generated.

The participating organizations are encouraged to examine this proposed planning document closely to make sure that the various metrics and related data requirements are clearly and correctly specified. They are further encouraged to offer any improvements that will enhance the quality and usefulness of the pilot project.

Finally, the participating organizations are encouraged to organize themselves in any way that would enhance the success of the pilot project. This might include, for instance, inclusion of DLA personnel, HQ AFMC/LG personnel, representatives of MAJCOMS and other potential stakeholders in the execution and "ownership" of the pilot project.

VIII. RESOURCE REQUIREMENTS

Resource requirements for the implementation of this pilot project (e.g., people, travel, related expenses) would include costs associated with the participation of MIT personnel in this pilot project. Additional resource requirements from the participating organizations would include the cost of monitoring the pilot project, additional data collection costs, and meetings. Further costs may entail investments by the participating supply organizations to ensure the timely availability of the required repair parts and materials for the end-items being studied in the pilot project.

IX. EXPECTED DELIVERABLES AND BENEFITS

Expected deliverables include:

- Briefings, as required, to Air Force leadership;
- Results of site-visits and meetings related to the pilot project;
- Documentation of the pilot project, including experimental design, data sources, principal findings and recommendations for more effective metrics;
- New analytical process for identifying and validating new metrics that the Air Force can use more widely to drive transformational change;

- High-level communication of principal findings to a wide audience of decision-makers in the Air Force, as well as to other policymakers, as appropriate.

The pilot project is expected to generate the following types of benefits:

- Improvements in the efficiency and effectiveness of the US Air Force's military avionics sustainment system through the use of more effective metrics (better resource allocation tied to a proper set of metrics; fostering better prioritization of repair and supply actions);
- Showing the impact of depot maintenance on the readiness of the combat units;
- Improved analytical framework for evaluating tradeoffs and better decision-making (providing an analytical link between *incremental* improvements at the local level and the consequent *incremental* improvements at the system-wide level);

Principal beneficiaries will include warfighters, as well as depot repair and supporting supply organizations. The design and execution of the pilot project is also expected to benefit the LSI industry partners by demonstrating a scientifically rigorous, relatively inexpensive and effective way for improving their performance metrics.

X. MAJOR TASKS AND PROJECT SCHEDULE

Major tasks to be undertaken in implementing the pilot project and the related project timetable are presented below.

Major Tasks/Activities	**Location**	**Timetable (Notional for tasks not yet completed)**
INITIAL ASSESSMENT PHASE (Includes previously completed tasks)		
TASK 1: Conduct Initial (Precursor) Metrics Research ***(Completed)***	Cambridge, MA	Dec 01-May 02
• "House of Metrics" Research	Cambridge, MA	Dec 01-May 01
• Metrics data collection and analysis for avionics end-items	Cambridge, MA	Jan–Jul 02

TASK 2: Develop Preliminary Design of the Pilot Project -- "New Metrics", including "New Operating Rules" ***(Completed)***	OO-ALC	Jun-Sept 02
• Preliminary design of pilot project – kick-off discussions	OO-ALC Cambridge, MA	July 8-10, 02
• Preliminary experimental design	Cambridge, MA	Jul-Aug 02
• Develop operational plan	OO-ALC; WR-ALC; AFMC/LG	Aug 02
• Review operational plan and provide feedback	OO-ALC; WR-ALC; AFMC/LG; Cambridge, MA	Sep - Oct 02
TASK 3: Finalize Pilot Project Operational Plan and Technical Experimental Design	OO-ALC; WR-ALC; AFMC/LG; Cambridge, MA	Nov –Dec 02
TASK 4: Execute Pilot Project	OO-ALC; WR-ALC; AFMC/LG	Jan – Dec 03
TASK 4: Analyze Interim Results and Prepare Report	Cambridge, MA	Jan -March 04

XI. NEXT STEPS

The following action steps are recommended to ensure the successful initiation of the pilot project:

- Review and approval of the proposed implementation plan by the participating stakeholder organizations, as well as any feedback from them regarding any improvements in the proposed implementation plan.

- Development of a general understanding among the participating organizational entities for closer working relationships among them and for concerted action by them in support of the pilot project and the required data collection and monitoring efforts.

- Implementation of the required data collection and monitoring methods and protocols to make sure that the data requirements for the proposed outcome metrics, enabling metrics, confounding factors and control variables, as well as other data needs, can be met on a timely and on-going basis.

- Provision of the required data on all metrics as detailed above for the period preceding the initiation of the pilot project for the development of all pretest data necessary for analytical purposes to estimate the effects of the proposed new metrics.

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K. Bozdogan and J. Sussman, "Enterprise Integration Focus Team Research Status," LSI Co-Leads Meeting, Massachusetts Institute of Technology, Cambridge, MA, 12 December 2000.

K. Bozdogan, J.Lengyel, J. Sussman and L. Williams, "Goals, Objectives and Metrics: Research Overview," LSI Co-Leads Meeting, Massachusetts Institute of Technology, Cambridge, MA, 1 August 2001.

K. Bozdogan, J. Lengyel, J. Sussman and T. Peterson, "Goals, Objectives and Metrics: Overview," LSI Steering Group Meeting, Warner Robins, GA, 19 December 2001.

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J. Hauser, "Applications of Metrics Thermostat," LSI Co-Leads Meeting, Massachusetts Institute of Technology, Cambridge, MA, 12 December 2000.

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ATTACHMENT A
GLOSSARY

ACC	Air Combat Command
AETC	Air Education and Training Command
AFB	Air Force Base
AFMC	Air Force Materiel Command
AFR	Air Force Reserve
ALC	Air Logistics Center
ANG	Air National Command
AWP	Awaiting Parts
AWP-F	Awaiting Parts, Parts Supportable
AWP-G	Awaiting Parts, Parts Required
BIE	Base Issue Effectiveness
BOM	Bill of Materials
BSE	Base Stockage Effectiveness
CANN	Cannibalization
CND	Cannot Duplicate
CONUS	Continental United States
CRI	Consolidated Repairable Inventory
CSI	Consolidated Serviceable Inventory
DFLCC	Digital Flight Control Computer
DLA	Defense Logistics Agency
DMAG	Depot Maintenance Activity Group
DMT	Dual Mode Transmitter
DoD	Department of Defense
DRILS	Depot Repair Information Local Server
EIT	Enterprise Integration Team (of Lean Sustainment Initiative)
EOQ	Economic Order Quantity
ERO	Equipment Repair Order
EXPRESS	Execution and Prioritization of Repair Support System
FMC	Fully Mission Capable
FMS	Foreign Military Sales
GAO	General Accounting Office
HQ AFMC	Headquarters, Air Force Materiel Command
HUD EU	Heads-Up Display Electronic Unit
IE	Issue Effectiveness
JRIU	Jettison Remote Interface Unit
LG	Logistics
LGF	F-16 Logistics Requirements Division
LGFBR	F-16 Logistics Analysis Section (within LGF)
LGS	Logistics Supply Division
LNA	Low Noise Amplifier
LPRF	Low-Power Radio Frequency
LRT	Logistics Response Time
LRU	Line Replaceable Unit

LSI	Lean Sustainment Initiative
LYPF	F-15 Logistics Analysis Branch
LYPO	F-15 Avionics Production Branch
MAJCOMS	Major Commands
MALA	F-16 Avionics Production Branch
MC	Mission Capable
MFD	Multi-Function Display
MICAP	Mission Capability
MIT	Massachusetts Institute of Technology
MLPRF	Modular Low-Power Radio Frequency
MRIU	Missile Release Interface Unit
MRO	Maintenance, Repair and Overhaul
MSC	Mode Select Coupler
MT	Maintenance Technicians
MTC	Maintenance Technicians Cross-Trained
NCRSR	Normal Customer Requirement Satisfaction Rate
NM	Materiel Manager
NMC	Not Mission Capable
NRTS	Not Repairable This Station
NSN	National Stock Number
OCONUS	Outside the Continental United States
OO-ALC	Ogden Air Logistics Center
O&ST	Order and Ship Time
OWO	On Work Order (When an end-item is moved from AWP-G to OWO status)
PACAF	Pacific Air Forces
POS	Primary Operating Stock
QDR	Quality Deficiency Report
RGA	Rate Gyro Assembly
RO	Requisition Objective
RSP	Readiness Spares Packages
RTOK	Retest Okay
RTS	Repairable This Station
SBSS	Standard Base Supply System
SE	Stockage Effectiveness
SMAG	Supply Management Activity Group
SPO	System Program Office
SRU	Shop Replaceable Unit
SSC	Shop Service Center
TNMCM	Total Not Mission Capable Maintenance
TNMCS	Total Not Mission Capable Supply
USAF	United States Air Force
USAFE	United States Air Forces Europe
USGS	United States Coast Guard
UCRSR	Urgent Customer Requirements Satisfaction Rate
WCRSR	Weighted Customer Requirements Satisfaction Rate
WR-ALC	Warner Robins Air Logistics Center

APPENDIX B:

Sample Part Usage Data Extrapolated From DRILS

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Table B1: MLPRF Bill of Material Usage Rates

	Jul-01	Aug-01	Sep-01	Oct-01	Nov-01	Dec-01	Jan-02	Feb-02	Mar-02	Apr-02	May-02	Jun-02	Total
DRILS Production Totals	33	56	43	55	61	42	19	37	39	62	42	49	**538**
ITS Production Totals	43	55	37	50	59	40	53	43	45	57	41	42	**565**

ITEM	Jul-01	Aug-01	Sep-01	Oct-01	Nov-01	Dec-01	Jan-02	Feb-02	Mar-02	Apr-02	May-02	Jun-02	Total
R/R 2A14 Low Noise Assy	10	17	12	26	26	18	8	13	16	38	26	25	**235**
%	30.30%	30.36%	27.91%	47.27%	42.62%	42.86%	42.11%	35.14%	41.03%	61.29%	61.90%	51.02%	**43.68%**
R/R 2A2 Frequency	4	11	6	6	10	10	2	3	11	13	7	12	**95**
% Synthesizer Assy	12.12%	19.64%	13.95%	10.91%	16.39%	23.81%	10.53%	8.11%	28.21%	20.97%	16.67%	24.49%	**17.66%**
R/R 2A3 Reference	5	6	5	11	6	11	4	2	4	9	4	16	**83**
% Oscillator Assy	15.15%	10.71%	11.63%	20.00%	9.84%	26.19%	21.05%	5.41%	10.26%	14.52%	9.52%	32.65%	**15.43%**
R/R 2A5 Radar Receiver	5	9	4	12	9	8	2	5	4	8	9	8	**83**
% Assy (AN/APG-68)	15.15%	16.07%	9.30%	21.82%	14.75%	19.05%	10.53%	13.51%	10.26%	12.90%	21.43%	16.33%	**15.43%**
R/R 2A4 Transmit Microwave	4	17	4	1	6	6	2	5	3	9	6	5	**68**
%	12.12%	30.36%	9.30%	1.82%	9.84%	14.29%	10.53%	13.51%	7.69%	14.52%	14.29%	10.20%	**12.64%**
R/R 2A8 Sampled Data CCA	7	4	3	5	3	4	2	5	4	7	3	4	**51**
%	21.21%	7.14%	6.98%	9.09%	4.92%	9.52%	10.53%	13.51%	10.26%	11.29%	7.14%	8.16%	**9.48%**
R/R 2A11 Controller	0	5	1	7	3	2	1	2	0	2	2	1	**26**
% Analog CCA	0.00%	8.93%	2.33%	12.73%	4.92%	4.76%	5.26%	5.41%	0.00%	3.23%	4.76%	2.04%	**4.83%**
R/R 2A1 Freq. Multi	3	1	2	1	2	0	0	3	1	3	7	2	**25**
%	9.09%	1.79%	4.65%	1.82%	3.28%	0.00%	0.00%	8.11%	2.56%	4.84%	16.67%	4.08%	**4.65%**
R/R 2PS1 MLPRF Low	1	3	1	3	4	2	0	2	1	2	3	2	**24**
% Voltage Power Supply	3.03%	5.36%	2.33%	5.45%	6.56%	4.76%	0.00%	5.41%	2.56%	3.23%	7.14%	4.08%	**4.46%**
R/R 2A13 CPU	0	3	2	2	2	1	0	0	0	1	3	1	**15**
% Controller CCA	0.00%	5.36%	4.65%	3.64%	3.28%	2.38%	0.00%	0.00%	0.00%	1.61%	7.14%	2.04%	**2.79%**
R/R 2A10 Controller Interface	3	0	0	0	1	1	0	0	2	0	0	1	**8**
%	9.09%	0.00%	0.00%	0.00%	1.64%	2.38%	0.00%	0.00%	5.13%	0.00%	0.00%	2.04%	**1.49%**
R/R NOC04 Waveguide Assy	0	1	0	1	0	0	0	0	1	1	0	2	**6**
%	0.00%	1.79%	0.00%	1.82%	0.00%	0.00%	0.00%	0.00%	2.56%	1.61%	0.00%	4.08%	**1.12%**
R/R NOC08 Dummy Load	0	0	1	0	1	0	0	0	0	1	1	2	**6**
%	0.00%	0.00%	2.33%	0.00%	1.64%	0.00%	0.00%	0.00%	0.00%	1.61%	2.38%	4.08%	**1.12%**
R/R 2A6 High Res Alt	1	0	0	0	1	2	0	0	0	0	0	0	**4**
%	3.03%	0.00%	0.00%	0.00%	1.64%	4.76%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.74%**
R/R NOC01 RF Micro Switch	0	0	1	0	1	0	0	0	0	1	1	0	**4**
%	0.00%	0.00%	2.33%	0.00%	1.64%	0.00%	0.00%	0.00%	0.00%	1.61%	2.38%	0.00%	**0.74%**

Table B1: MLPRF Bill of Material Usage Rates (continued)

	Jul-01	Aug-01	Sep-01	Oct-01	Nov-01	Dec-01	Jan-02	Feb-02	Mar-02	Apr-02	May-02	Jun-02	Total
R/R NOC03 Waveguide Gasket	0	0	1	0	0	0	0	1	0	1	0	0	**3**
%	0.00%	0.00%	2.33%	0.00%	0.00%	0.00%	0.00%	2.70%	0.00%	1.61%	0.00%	0.00%	**0.56%**
R/R M1 ETI Meter	0	0	0	0	0	0	0	0	0	1	0	1	**2**
%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.61%	0.00%	2.04%	**0.37%**
R/R Mounting Bracker	0	0	0	0	0	0	0	0	0	0	1	1	**2**
%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	2.38%	2.04%	**0.37%**
R/R Jackscrew	0	0	0	0	0	0	0	0	0	0	1	1	**2**
%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	2.38%	2.04%	**0.37%**
R/R F2 Filter	0	0	0	0	0	0	0	0	0	0	1	1	**2**
%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	2.38%	2.04%	**0.37%**
R/R F1 Filter	0	0	0	0	0	0	0	0	0	0	1	1	**2**
%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	2.38%	2.04%	**0.37%**
R/R NOC11 Matrix Board	0	0	1	0	0	0	0	0	0	0	0		**1**
%	0.00%	0.00%	2.33%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.19%**

Table B2: LNA Bill of Material Usage Rates

	Jul-01	Aug-01	Sep-01	Oct-01	Nov-01	Dec-01	Jan-02	Feb-02	Mar-02	Apr-02	May-02	Jun-02	Total
Total Produced (DRILS)	22	21	37	43	21	8	13	0	0	0	4	17	**186**
ITEM													
R/R A1 Receiver Protector	16	16	23	33	17	7	11	0	0	0	1	1	**125**
%	72.73%	76.19%	62.16%	76.74%	80.95%	87.50%	84.62%	0.00%	0.00%	0.00%	25.00%	5.88%	**67.20%**
R/R A2 FET Amp	14	12	20	29	14	6	11	0	0	0	3	4	**113**
%	63.64%	57.14%	54.05%	67.44%	66.67%	75.00%	84.62%	0.00%	0.00%	0.00%	75.00%	23.53%	**60.75%**
R/R A3 Stalo Assy	12	3	3	7	2	1	0	0	0	0	3	2	**33**
%	54.55%	14.29%	8.11%	16.28%	9.52%	12.50%	0.00%	0.00%	0.00%	0.00%	75.00%	11.76%	**17.74%**
R/R A4 IF Assy	3	1	6	4	0	0	0	0	0	0	1	1	**16**
%	13.64%	4.76%	16.22%	9.30%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	25.00%	5.88%	**8.60%**
R/R Hard Line	0	0	0	0	0	0	0	0	0	0	1	0	**1**
%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	25.00%	0.00%	**0.54%**